Design for Movement:

Block Pattern Design for Stretch Performancewear

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ABSTRACT

Pattern drafting techniques for woven block patterns have been well established. Applying existing techniques with modifications to generate patterns for modern stretch fabrics can be successful but it is often at a cost. In the development of a stretch pattern, an acceptable fit cannot be guaranteed merely by using a rationalised simple pattern profile shape.

Producing a pattern, without darts, to closely adhere to the contours of the body without restricting movement, is a contradiction in design terms. In woven fabric, darts and ease are used to manipulate the fabric around the form and allow movement. However, in stretch knit fabric the development of a block pattern involves the synthesis of information from a variety of disciplines and requires a more specialist approach.

This study has endeavoured to show that a new interpretation of pattern design principles is needed to create an improved stretch block pattern for stretch knit performancewear. This work has been refined based on a new method of classifying stretch fabric parameters and personal observation of the effect of stretch distortion characteristics and the changes that occur in the two-dimensional pattern profile, when stretched to conform to the three-dimensional body.

The results of this study will provide a more scientific and practical approach to assessing stretch fabric parameters as an integral part of block pattern design for stretch performancewear. The fabric stretch potential has been maximised to contour the body for optimum fit, providing comfort and mobility without the need for redistribution of the fabric when activity ceases. A method of creating a stretch block pattern from direct measurements to replicate the body shape and proportions was devised which can be reduplicated.

This study addresses primarily the designer/pattern cutter who has a passion for good fit, which enhances comfort and mobility, who does not necessarily have a scientific background. However this study is relevant to the textile technologist concerned with proposing a standard to compare stretch fabrics for garment production. It should also appeal to the computer programmer concerned with the link between 3D body scanning and interpreting the body profile accurately in the 2D pattern draft.

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Terms and Definitions

Bias vectors	Vertical and horizontal components of fabric stretch characteristics derived from course, wale and bias stretch.
Crutch (Crotch)	Base of the torso where the legs join the body.
Dress stand	A static representation of the human form usually constructed from a rigid material. It can be referred to as a dummy, mannequin, manikin, stand or form.
Fabric	Woven, knitted or felted material.
Fork	Base of the torso where the legs join the body.
Garment	Article of dress, clothing, outward and visible covering of the body.
Tare stretch	Minimum stretch to fit form without wrinkling.
Toile	Cloth pattern representation

Author Declaration

1. During the period of registered study when this dissertation was prepared, the author has not been registered for any other academic award or qualification.

2. The material included in this dissertation has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

P Watkins

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Preface

My interest in this field has grown and developed over many years. My mother is a gifted dressmaker with no formal training and my father is a skilled craftsman, they are always disassembling, modifying and reassembling items from their relevant fields. As a child and still now, I spend time unpicking garments to scrutinise the three dimensional form in a two dimensional plane, a method 'picked up' from my own mother. When my mother made garments for me, she would take many fittings to get it just right, as I was extremely demanding in my requirements. Though in hindsight I'm not sure whether this was for her benefit or mine, but it left me with an overriding passion for fitting for comfort and movement. My technical skills expanded in the workroom of a Manchester fashion house. I then became a trainee designer with a rainwear company and worked in all areas of design and production, which during the 1960's was as good as any formal college training. Later I set up my own design company and worked as a consultant for a leading manufacturer of performance textiles. Having children of my own, history was repeating itself. I designed gymnastic leotards for my daughters, which had to meet their exacting specifications. My daughters 'simply' wanted garments that were comfortable and didn't constantly need readjusting. I found their requirements were not unique and was soon asked to design and make leotards for the entire club! This was my introduction into the design of a uniform stretch leotard, in which the proportions ranged from tots to teens with different body shapes and postures. The challenge had fuelled my inspiration and gave me the momentum to continue refining the basic leotard for individual performance needs.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 BACKGROUND TO STRETCH BLOCK PATTERN DESIGN FOR MOVEMENT

Garments for specific activities and the corresponding development of stretch fabrics have been evolving since before the turn of the century. This, combined with industrial development and technical innovation, has occurred as a consequence of greater participation in sporting activities and has resulted in a plethora of stretch garments for diverse applications flooding the market. However, the understanding of how to optimise the stretch potential in pattern design for performancewear is not well developed and it is this area to which this thesis is directed.

1.1.2 Definition of Stretch

A stretch fabric usually describes a fabric that stretches easily, has an extension of at least 10% and reverts quickly to its original state when relaxed (Denton 1972:25). The three prerequisites for a stretch fabric are:

1. The structure must deform significantly when subjected to relatively small loads.

2. The fabric should be engineered to recover rapidly to its original state on relaxation, irrespective of how much or how frequently (within reason) it is extended. This is achieved by way of the internal recovery forces in the fabric structure. They are the twisting and bending forces of either yarn or fibre or both and the bending and unbending forces within the fabric structure itself. The stretch characteristics of the fabric are only produced by the capability of the extended or stretched fabric to contract considerably on relaxation.

3. To maximise rapid recovery from extension with little or no permanent growth. The fibres and yarns must have sufficient freedom from internal constraints and minimum friction between yarns in order to assist recovery.

Stretch fabric characteristics can be developed at the fibre, yarn or fabric structure stage. Most man-made fibres can be treated by mechanical and chemical processes in order to produce yarns with some degree of stretch and recovery. Although not all knit stretch fabrics have stretch properties suitable for garments that conform to the body contours.

1.1.3 Stretch for Performancewear

The invention of elastane fibres was a major contributory factor in the development of stretch performancewear. In 1959 DuPont patented 'Lycra'. It was invented as a replacement for rubber, which perished easily and was heavy and hot to wear. This synthetic fibre was so revolutionary that a new classification had to be found, so this segmented polyurethane became known as an elastane or elastomeric fibre and called Spandex in the USA (BARNES 1994:9). Lycra® (hereinafter referred to as elastane) was first used in corsetry where its power to weight ratio was exploited to the full in girdles and corselettes. Throughout the 1960's elastane was used in underwear but instead of robust corselettes there was the *no bra* look. The use of elastane was highly specialised and considered desirable because it was expensive. It appeared on the ski slopes taking the bag and sag out of the pants of the rich and famous and also changed the image of swimwear forever. The continued development of elastane by DuPont has ensured its incorporation in a wide variety of fabrics for innumerable applications. The elastane filament is always used in conjunction with an inelastic companion fibre. Fabrics can be enhanced by the inclusion of elastane; the elastane yarn is invisible and only the benefits of stretch can be perceived.

1.1.4 Performancewear Described

Performancewear indicates clothing that fulfils a function, facilitates movement, and enhances the wearer's performance. These clothes are not intended to be purely fashionable, however, a contemporary feel may be desirable. For the sports participant today the garment design and textile material can help to trim those vital few seconds off a winning performance. The prime considerations of a functional garment design are comfort and mobility, but not necessarily in that order. The development of a comfortable functional garment for activewear is challenging, as a number of factors have to be considered and finely balanced. Literature to date suggests ways of achieving stretch block patterns to meet these requirements. Usually these are either for fashion garments or limited to specific parts of the body and are implemented with varying degrees of success.

1.1.5 Comfort

Defining comfort is almost impossible because the perception of physical comfort is subjective. Although there is not a universally accepted definition of comfort it is important to recognise the main physiological and psychological factors affecting comfort. Physical comfort relates to the effect of the external elements, either physiological or psychological. It is described in The Concise Oxford Dictionary (1980:201) as 'freedom from pain' and general 'well being'. This definition seems to be inadequate, particularly when applied to sports participants who often expect and endure various levels of pain. Slater (1986:158) attempts a qualitative definition in which comfort is defined as *"a pleasant state of physiological, psychological, physical harmony between a human being and the environment"*. It is, therefore, a neutral sensation as one is unaware of comfort, both psychological and physiological (Smith 1986:23). Most individuals find the positive sensation of comfort insignificant and have a greater awareness of the negative sensation of discomfort, which only becomes apparent when the body is adversely affected. (See Figure 1)

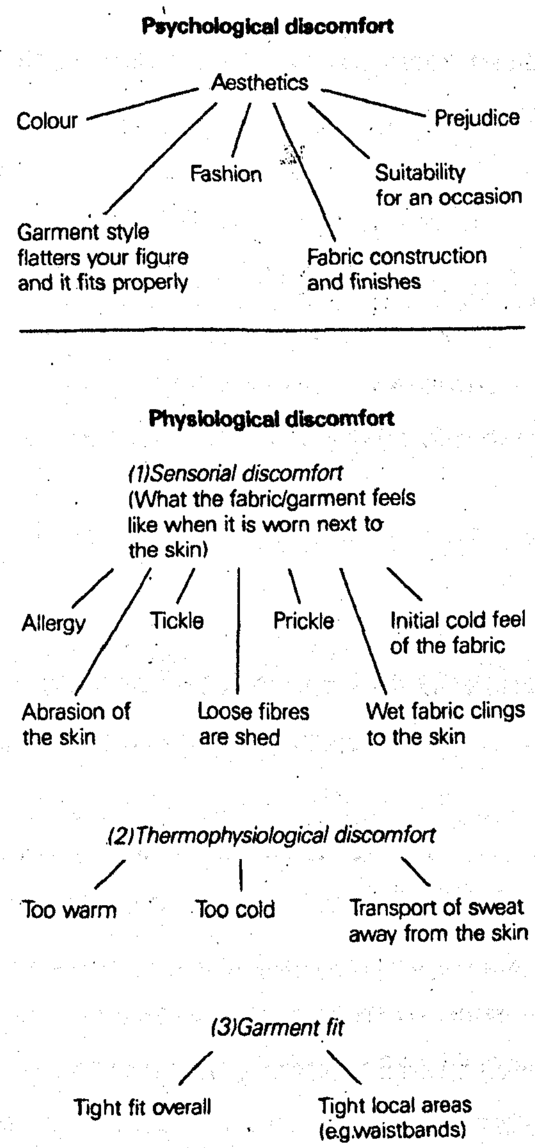


Figure 1 - Psychological and Physiological Discomfort.
Source: Smith (1986:23)

Psychological factors are inextricably linked with physical factors in determining levels of comfort: idiosyncrasies; prejudices; preferred environment; preferred temperature; posture; pain sensitivity; effects of stress; level of embarrassment; need for privacy; body consciousness; preferred garment fit; tactile sensitivity. Textile properties including thickness and weight, fibre content and the nature of fabric structure, particularly the next-to-skin surface, are obviously crucial factors for tactile comfort. (Harnett 1976-1984:3-11).

One of the main characteristics of the human body is that it produces heat that is dissipated in the form of sweat, which, by evaporation from the skin surface, affects cooling. Sweating is not in our conscious control; *insensible* sweating happens all the time and evaporates before reaching the skin's surface; *sensible* sweating occurs from over heating, from exercise or hot temperature (Bryson 1996:3). Most sweat glands are concentrated under the breast, the armpit and where the skin is thinnest around the crotch. Accumulation of sweat on the skin and wet fabric dragging against the skin can accentuate an undesirable garment fit and cause discomfort.

1.1.6 Mobility and Fit

In terms of physical comfort, a stretch knit fabric does respond particularly well during movement. Mobility may be enhanced or restricted by the garment fit and how closely it conforms to the body and the pressure exerted by the retracting stretch characteristics of the fabric. When contoured over the body a stretch garment should fit well, and offer mobility and comfort without displacing or straining the fabric. There is a high degree of inconsistency between manufacturers with regard to both sizing and fit models. Some manufacturers of stretch garments are of the opinion that because a garment stretches it will automatically stretch in the right places to give an acceptable fit and ease of movement. This is a fundamental misunderstanding of stretch characteristics.

A stretch garment that conforms closely to the body contours may offer a high degree of mobility, be fashionable, aesthetically pleasing, conform to an ideology or culture of a specific sporting activity, all of which should lead to psychological comfort. However, the contoured stretch garment can still engender some dissatisfaction. LaBat and DeLong in their study *Body Cathexis and Satisfaction with Fit of Apparel* suggest that:

> A factor that may contribute to women's dissatisfaction with the body is that fashionable clothing reflects a standard they do not fit. When clothing does not fit, the consumer may perceive the cause as related to the body and not the clothing, with resulting negative feelings about the body. (LaBat and DeLong 1990:43)

It is the relationship between the body shape, proportions and posture and the method and assumptions implicit in the construction of the garment pattern profile that impels the quality of the garment fit. Stretch garment-to-body fit disparities, can often be the root cause of body dissatisfaction and the stretch garment that constantly has to be rearranged in order to feel more comfortable only adds to this dissatisfaction. Therefore, the importance of fit to enhance psychological and physical comfort is crucial in performance clothing.

1.1.7 Block Patterns for Stretch

A block pattern is a template that is used as a basis for style development. Establishing a basic block pattern for any stretch fabric is a complex balance of interrelated variable factors including type of fit required, type of fabric, direction of stretch (uni-axial or differing bi-directional) and degree of stretch.

Block pattern construction for non-stretch fabrics is well established; there are numerous technical books on pattern design, some of which have sections on constructing block patterns for stretch fabrics. Usually these are for fashion (static) garments and not functional (dynamic) garments. The use of stretch fabrics in all types of apparel is becoming more important as the benefits of comfort, fit and shape retention are increasingly desired. A number of studies for woven fabrics have been carried out on garments that are not stretched to closely contour the body. They have contributed to establish the minimum degree of stretch required for optimum fit and comfort through assessing fabric extensibility and the impact on garment performance (Kirk Jr and Ibrahim 1966:37-47).

There are studies (Ziegert and Keil 1988:54-64) investigating pattern design for stretch contoured garments that have proportionately reduced existing block patterns horizontally and vertically, based on linear fabric extensibility, which could be a good starting point. However, the effects of movement and fabric curvilinear stretch distortion characteristics on the garment pattern profile were not considered. Also the pattern was limited to areas of the body that are relatively uncomplicated to fit and this effectively circumvents the process of designing a garment to encompass the whole torso and limbs. The need for a practical and consistent approach to block pattern design for a complete bodysuit is the reason that this study has been undertaken.

1.2 AIM AND OBJECTIVES

1.2.1 Aim

The aim of this research is to formulate block pattern draft rules for a stretch bodysuit that encompasses both torso and limbs and accommodates required movement with specific regard to stretch fabric behaviour.

1.2.2 Objectives

To achieve this aim, the specific objectives are:

1. To develop quantitative and qualitative procedures for the evaluation of fabric extensibility and curvilinear stretch characteristics.

2. To understand the anatomical movement of joints, muscles and the relationship of skin stretch deformation and how this knowledge can be applied to stretch garment pattern construction.

3. To develop and apply a new model for stretch block pattern construction which will enable manufacturers, designers and students to have a deeper understanding of basic block pattern design when transferring from a flat pattern shape to the contoured form.

1.3 KEY AREAS FOR INVESTIGATION AND EVALUATION

1.3.1 Design Strategy

This study is a practical approach to block pattern generation for stretch fabrics and concentrates on the interrelated areas that directly affect the contour fit of the stretch block pattern, designed for enhanced comfort and mobility. These are:

- stretch fabric characteristics;
- mobility;
- anthropometry;
- pattern design;
- fit evaluation.

There are difficulties in viewing these aspects in isolation, as there is inevitably a degree of overlap. However, in order to produce a block pattern design specification, all these factors have to be considered and finely balanced. An overview of the entire design process is shown in a strategic flowchart in Figure 2.

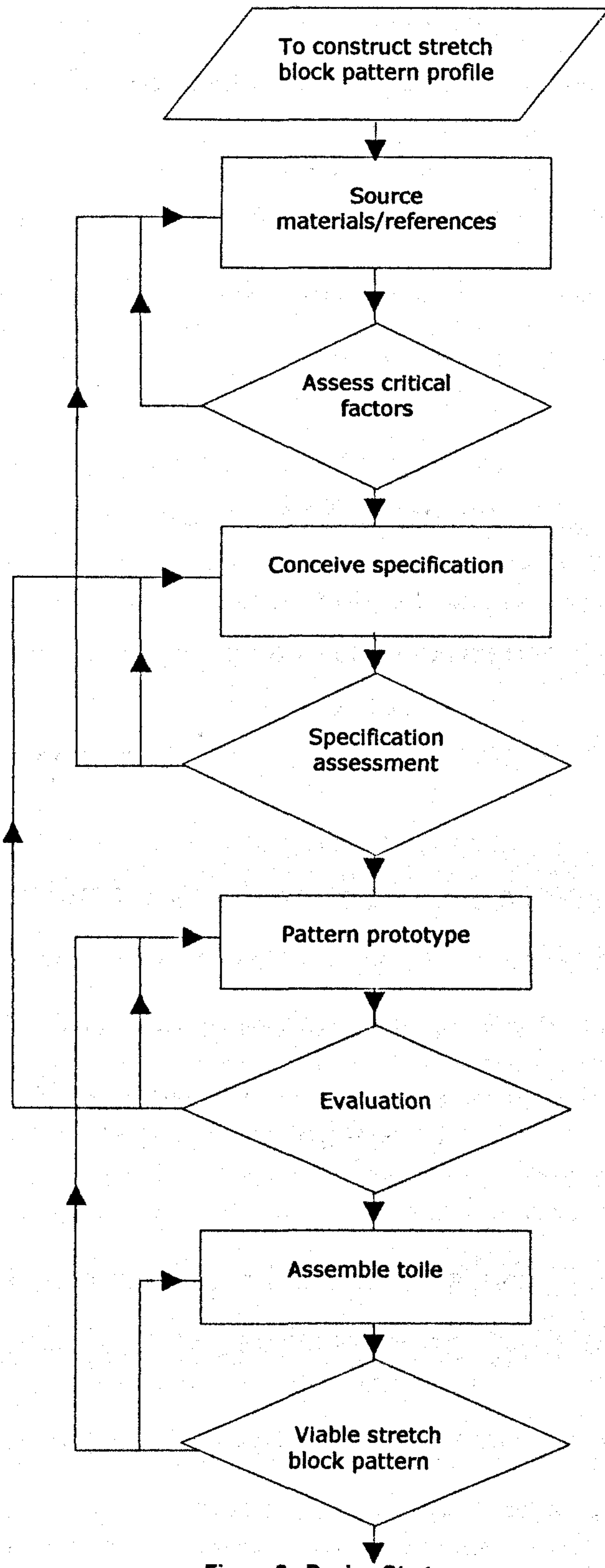


Figure 2 - Design Strategy

1.3.2 Stretch Fabric Characteristics

The development of knit stretch fabric technology is increasingly sophisticated. The interrelationship of fibre composition, yarn construction, stretch fabric type, production process and application of various finishing techniques all contribute to the stretch performance characteristics.

The performancewear designer or pattern technologist does not necessarily need an in-depth knowledge of the complex minutiae of a textile profile. However, the designer should be sufficiently familiar with textile characteristics to assess the benefits and implement the relevant test methods suitable for the specific application.

The study of stretch characteristics is primarily aimed at the designer who, like the author, may not have had the benefit of a scientific background.

The analysis of stretch characteristics is both subjective and objective: subjective in relation to the aesthetics of visual stretch: objective in relation to a stretch classification system identifying the degree of elongation uniaxially in the course, wale and bias direction.

A visual appreciation of fabric stretch distortion characteristics is central to the designer's fit analysis and evaluative skills when developing a stretch block pattern to conform to the undulating body profile.

To promote the understanding of stretch characteristics from a visual perspective, a series of experiments were developed to visualise and record the stretch distortion of a warp knit stretch fabric when extended by fixed increments up to twice the sample length.

This enables the designer to appreciate geometrically the effects of fabric stretch curvilinear distortion for transposition, when viewing a stretch garment as integrated geometrical shapes, in the relationship of the 2D (two dimensional) pattern geometry to the 3D (three dimensional) form.

It is difficult to consistently manufacture stretch fabric with specific stretch characteristics as small variations within production tolerance impact on the finished fabric. Even identical production specifications produce fabric that can vary in stretch performance between batches.

There are many documented methods for assessing fabric stretch extension, however, these are usually directed towards textile technologists and are difficult for the designer to interpret and apply as the variations in fabric sample size and load can be confusing. British Standard test method (BS 4952:1992:1-12) is limited because although stretch elongation to break point and stretch and recovery can be quantified, it does not go far enough to identify a method for recording stretch extension for pattern construction.

The designer/pattern technologist needs to be able to objectively quantify stretch extension as part of the stretch block pattern reduction process. Therefore, exploratory mechanical force extension testing was undertaken to determine an appropriate dimension for the stretch fabric sample to be used in the extension testing. The Instron Tensile Testing Apparatus was then used to identify the forces involved in stretch fabric extension in the course, wale and bias. Using the results of the mechanical force extension testing, a hanger load test was tailored to specifically meet the needs of the designer/pattern technologist.

A comprehensive understanding of knit stretch fabric characteristics related to body profiling is crucial to the stretch block pattern development process.

1.3.3 Mobility

The recording of movement for analysis through notation, photography and three-dimensional visualisation has been developed primarily to assist training and optimise performance and is well documented. This plethora of material holds enormous insights for the designer. A comprehensive understanding of anatomical movements of joints and muscles and the extent to which skin stretches to accommodate movement is important as this has a significant influence on garments designed for individual activities.

During movement, it is the interrelationship between the stretch fabric characteristic, the garment pattern profile and the body profile, particularly the flexion, extension and rotation of the upper arm at the junction with the torso and the leg in the crutch area, that impacts on the fit of the garment. The behaviour of the stretch garment-to-body fit relationship during a whole range of movements is paramount. Therefore, techniques for the precise measurement of specific movements have not been pursued in this study.

The area of interest in design for mobility is the way in which the stretch fabric conforms to the body with a consistent fit quality over an extensive range of movements. The focus was on increasing comfort by avoiding stretch fabric displacement during movement and eliminating the need for fabric readjustment to fit the body when motion ceased.

1.3.4 Anthropometry

Accurate anthropometric data has become vital in the clothing industry, not only for comprehensive garment sizing and grading but also for the pursuit of mass customisation. Measurement data can be amassed and collated quickly through the use of technology. Although automated body scanning is evolving rapidly at present there are limitations to consistently and accurately measuring and recording data. Movement of the subject can bring about errors and areas of crucial data can also be missing through shading for example under the arm and in the crutch area (Daanen 1998:111). Current garment sizing and grading charts are either taken from existing anthropometric data or, more usually, from outdated surveys or surveys modified for a specific target market. These surveys did not include dynamic measurements or information on body shape, proportions or posture. Disparities between manufacturers sizing systems are frustrating for the consumer, current garment sizes do not define the garment fit expectations or the proximity of the garment-to-body fit relationship so garments stating an actual body measurement for the size designation are difficult for the consumer to relate to without trying on the garment.

Existing data sets do not provide the measurements required to produce a stretch block pattern directly from body measurements. This study uses an amalgamation of available body measurement information and forms a superset, which includes many new measurements.

The measurements used in this study have been taken to provide a starting point in understanding, through pattern drafting techniques, to approximate the body contour profile. Given time, the number of measurements could be significantly reduced however the crucial measurements would still not be available from most existing size charts. Consequently the relevant measurements would have to be acquired through a measurement survey, either conducted by hand or by technological means.

Body measurement data and a computer model would be needed to produce either customised garments or a broad range of stretch contoured garments for both men and women. Although body scanning techniques for acquiring measurement data is crucial in further developing the stretch block pattern for industry, an in depth study of this technology was considered to be outside the scope of this study.

With the advent of automatic body scanning and associated data processing, the number of measurements should not present a problem in the future. It is the interpretation of the measurement data that is significant for computer modelling in pattern design systems. It is not body size, but body shape, proportions and posture that are the key to producing a body contoured stretch garment to provide a good fit facilitating comfort and mobility without fabric displacement. This study concentrates on dynamic pattern production replicating body shape and posture.

1.3.5 Pattern Design

The use of technology for pattern generation can speed up the time consuming process of pattern design. Once all of the measurements and drafting rules have been computerised, the final pattern draft can be integrated into the garment production process. In this study a computer spreadsheet was used to store, manipulate and output the stretch block pattern pieces directly onto paper.

Familiarity with the manual process is nevertheless essential particularly in the development of contoured stretch patterns. As Shoben has noted:

> Computers do not pass on or teach us skills to design cut and produce garments *they only enable us to organise ourselves in a far more efficient manner*. (Shoben 1996:19)

Consequently, it is important for the designer or pattern technologist to have a comprehensive understanding of the basic craft skills. As Shoben attests;

> The use and blind obedience to block construction systems hinder the development of understanding of the underlying principals of pattern construction systems. (Shoben 1990:91)

It is valuable to go back to the basic pattern cutting techniques beyond the *'one size fits all'* school of pattern design:

1. To absorb the underlying principals of patterns designed to fit the contours of the body, be they natural or manmade.

2. To observe the drafting techniques and how patterns can be manipulated to achieve a specific objective either fit, function or design.

It is this overall understanding of the craft skill of pattern cutting; the relationship between the form, the flat pattern and the stretch fabric that impel the development of a successful pattern for stretch performancewear.

Block patterns for stretch fabrics are mainly adapted from block patterns for non-stretch woven fabrics. These, after modification, are proportionately reduced horizontally and vertically and they are then ready for stretch fabrics. These patterns are usually constructed taking the measurements from existing data sets. Drafting systems, to a greater or lesser extent usually make assumptions about the body shape, proportions and posture based on available measurements.

Traditionally block patterns are constructed interpreting a number of measurements which are derived from the measurement data and not from direct body measurements. However, in exploring the concept of patterns designed to fit the contours of the body the key is body shape and posture. With this in mind the drafting technique for the stretch block pattern was developed using direct body measurements.

1.3.6 Fit Evaluation of the Stretch Fabric Bodysuit

The bodysuit in this study is constructed from Coolmax®, a warp knit stretch fabric, which incorporates Lycra® and was produced by Penn Nylar. It is a performance fabric used extensively in sportswear to divert moisture away from the body to increase the comfort level for the participant during exercise as it does not cling to the body when wet, which can lead to post exercise chill.

Evaluating the fit and assessing levels of comfort and mobility is extremely complex. There is always a trade-off when designing a body contouring garment which allows complete freedom of movement because one still has the wrinkle factor either to design out or to accommodate, depending on the range of movement required. A compromise towards movement and comfort may be at the expense of the aesthetics of the garment fit when the body is at rest.

The assessment of comfort and fit is subjective because it is dependent on individual interpretation, the subject's perception at the time of testing and also the interpretation of descriptors used to illustrate the sensations of comfort and fit. Therefore, inconsistencies are inherent and impossible to eliminate. To obtain a more objective assessment of fit visually, the stretch toile used was printed with a 25mm grid to enable visualisation of fabric distortions. The observed localised distortion of the overall garments was evaluated and the conformity of the two-dimensional pattern to the three-dimensional body was assessed.

A Kennett and Lindsell Full Length, Size 12 dress stand was used and is referred to as Dolly. The dress stand was chosen as a development tool for its consistency, availability and to eliminate as many variables as possible. It was not possible to assess the toile, which were made for the dress stand, for a specific posture, mobility or comfort, as Dolly was inflexible!

Although Dolly was a size 12 the concept of introducing standard sizes for the stretch block pattern bodysuit is not explored in this study. It is body shape and posture that is the key to producing the new stretch block pattern, which was drafted from direct body measurements.

Before the quality of the garment fit can be assessed the garment fit parameters need to be stated. Therefore the contouring garment-to-body proximity relationship was loosely categorised and the garment fit quality expectations were interpreted and outlined. A fitting scheme was implemented as an aid to analysis and evaluation in the design development process. The fitting scheme was also used as a basis for the chart used in analysis and evaluation of the photographs taken of the subjects wearing the bodysuits.

For the assessment of fit, mobility and comfort, three subjects, Michael, Fiona and Natasha were chosen because they represented different body shapes and proportions.

To demonstrate the dynamic stretch and recovery of the test bodysuits a video 'Action Fit in Motion' featuring Fiona wearing two garments B and E, is provided with this thesis.

CHAPTER TWO

KNIT STRETCH FABRICS

2.1 INTRODUCTION TO KNIT STRETCH FABRICS

This chapter encompasses the development of stretch fabrics for performancewear, advances in stretch, the knit structure and the visualisation and evaluation of stretch characteristics.

Before considering the stretch characteristics of knit stretch fabrics it is advantageous to have an insight into their evolution. The history of stretch performance fabrics begins with the invention of nylon, the first synthetic fibre and then incorporates revolutionary elastane, rubber's synthesised alternative. The examination of simple knit structures is instructive as to how a knit fabric moulds readily to the contours of the body. Analysis of the stretch characteristics that empower the knit structure is vital. Performance fabrics can be manufactured from synthetic, manmade or natural fibres in any one of a number of combinations and using a variety of construction techniques to satisfy the end use. Figure 3 shows a key to the fibres and their classifications, some of which are elaborated on.

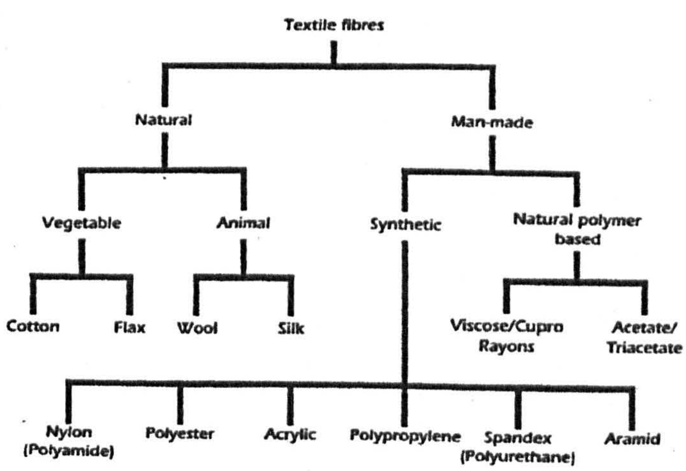


Figure 3 - Classification of Apparel Fabrics. Source: Southam and Bingham (1993:6)

2.2 DEVELOPMENT OF KNIT STRETCH FABRICS

The advent of nylon created a revolution in the fibre industry. In 1931 Wallace Carothers, a chemist in the DuPont company, reported research undertaken on molecules called polymers which were synthesised from petrochemicals; the invention was a melt spun fibre named polyamide. The chemicals were extruded through a spinneret. This process produces continuous filaments of considerable length, often as much as several kilometres. This polyamide was referred to commercially as 'nylon 66'; a number derived from its chemical structure. Hence the 'miracle fibre' nylon was spawned. Later research in 1938 by Paul Schlack identified a different form of polymer referred to as 'nylon 6'.

DuPont produced nylon commercially in 1939 and nylon stockings were first exhibited at the San Francisco Exposition in that year. Nylon proved valuable during the second world war where it not only replaced silk for parachutes, but was used for tents, ropes, lines and other military supplies. Even nylon stockings, a luxury, were much sought after on the black market. During the post war years there was a steady increase in new developments in manufactured fibres leading to the 'wash and wear' revolution in the 1950's and 1960's.

The next high point in the story of melt spun fibre technology was in 1941 at a company based in Manchester called Calico Printers Association, when co-collaborators Whinfield and Dickson invented polyethyleneterephthalate (PET) 'polyester' (Brunnschweiler 1992:22). The term polyester is a generic name used to describe any polymer consisting of a string of small chemical units held together by the ester group. The first public announcement of the new fibre was after the war in 1946, when it was referred to as 'Terylene' by ICI Ltd who negotiated world manufacturing rights except in the USA, where DuPont had the licence. It was registered by ICI as 'Dacron'. Polyester in many respects is similar to nylon, as it is tough with high abrasion resistance. Because the fibre is heat set it not only recovers well from creasing but also its low moisture absorbency allows it to be quick drying. In the 1950's the commercialisation of polyester on its own or in combination with natural fibres produced garments, which emerged from the wash 'wrinkle-free', dispensing with the time consuming job of ironing.

However, during the 1960's and 1970's synthetics fabrics fell from favour as they were, unlike natural fibres, hot and sticky to wear and were perceived as unable to 'breathe'. Generally, fabric sensation equates with fibre content and traditionally natural fibres were perceived to be more comfortable than synthetic fibres. This widely held belief could not be disputed before the development of technical performance fabrics, where complex factors (not just fibre content) contribute to the degree of comfort of the wearer. Synthetic filament yarns, through the process of texturing, can be engineered to produce fabrics which simulate or improve on the aesthetic and tactile qualities of natural fibres. With relatively high extensibility and good recovery from stretching, they resist creasing far better than natural fibres. Most synthetic fabrics are hydrophobic; this can be beneficial as it promotes rapid drying. Significant development in the manufacture of synthetic fibres has improved their reputation and there are now fabrics with particular attributes to suit every aspect of modern life (Handley 1994:29-30).

Contemporary fibres can enhance comfort, offer moisture management, environment protection, flame resistance, UV protection, encapsulate slow release fragrances, vitamins or medications, incorporate antibacterial functions, have a heat generating function, or utilise the thermocratic properties of fabrics, which respond to heat and change in colour. Microfibres that emulate silk when handled are used across the spectrum, from the softest lingerie to weatherproof performance garments. Microbubbles contained within the material produce secret built-in functions, like the release of perfume to give a pleasant aroma. Heat-generating fabrics have micro-encapsulated receptors which absorb heat from the body or other heat sources. The stored heat is then slowly released to the body as the body cools. In this technological age synthetic fabrics are becoming 'smart'; research is already underway into miniaturised circuitry which could mean that communication functions for entertainment or protection become an integral part of fabric design.

Toray, a Japanese company defines the spirit of the 1990's as being a quest to capture the mysteries of nature through the power of technology. In the final analysis the specific application is decisive as interactive fabrics progress to deliver the ultimate performance.

2.2.1 Synthetic Fibres and Fabrics

There are many comprehensive publications covering fibre and fabric technology. This overview features some of the synthetic fibre available on the market, describes specific fabric qualities and highlights aspects to be considered in relation to the entire design process for stretch performancewear.

All synthetic fibres are produced by a chemical extrusion method using a spinneret. This is a machine with metal discs pierced with tiny holes through which the syrup-like liquid is forced. As the polymer is drawn through the spinneret it solidifies into filaments. The shape of the holes in the spinneret determines the shape of the filament. Filaments can be produced in a number of cross-sectional shapes each imparting recognised characteristics on to the fibre. The performance characteristics of the fabric can be enhanced by the cross-sectional shape of these filaments.

2.2.2 Nylon

Nylon 66 and nylon 6 are stronger than cotton and retain most of their strength when wet. They have relatively high extensibility, recover well from stretching, resist creasing far better than natural fibres, are resistant to solvents and micro organisms and have excellent abrasion resistance. They are also hydrophobic, which is beneficial as it enables rapid drying. Nylon also responds well to a wide range of dyes.

An example of a standard nylon cross-section and a trilobal cross-section of Tactel® nylon fibre for performance fabric is shown in Figure 4

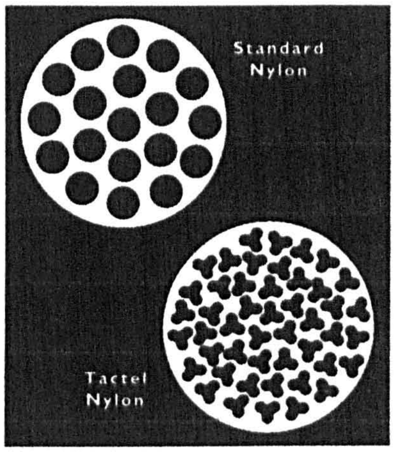


Figure 4 - Tactel Nylon. Source: Du Pont Technical Information (1996:21)

2.2.3 Polyester

The term polyester is a generic name used to describe any polymer consisting of a string of small chemical units held together by the ester group. Polyester in many respects is similar to nylon as it is thermoplastic and resistant to both microbiological attack and common solvents. The fibre has high abrasion resistance and it recovers well from creasing. Its low moisture absorbency promotes quick drying, unfortunately making it prone to static. Unlike nylon, polyester is one of the most difficult fibres to dye, however, this problem can be overcome chemically. Pilling, the formation of short broken fibres tangled together into small balls on the surface of the fabric caused by friction, is an undesirable characteristic associated with polyester. Polyester is used either on its own or is blended with other fibres. It contributes to easy care properties because of minimal creasing, has high abrasion resistance and the aesthetics of good drape and hand. These qualities make it suitable for use in a wide range of garments, particularly sportswear.

There are those with high insulative properties and the ability to wick moisture away from the body, which is excellent for sportswear.

2.2.5 Polyolephin

Olefin is a term used for a family of oil-based chemicals, the prefix 'poly' being added to denote those converted into long chain (polymerized) form (Ford 95:11). The two principle olefins are polypropylene (PP) and polyethylene (PE).

Polypropylene is used extensively in activewear. It makes an ideal skin contact layer because it is non toxic and has very low support for bacterial growth. It also has excellent thermal properties and the ability to rapidly transport perspiration away from the skin.

2.2.6 Microfibres

The first microfibres were produced commercially in Teijin in 1971. The generally accepted definition of a microfibre is a fibre, which is 1.0 decitex or less. In the USA, it is fibre of one denier or less.

Fine filaments were originally developed to emulate the aesthetic and tactile qualities of silk. However, microfibres go beyond imitation as they have inherent desirable qualities and aesthetic appeal. Initially woven microfibres were used to make weatherproof breathable fabrics. Micropores (air pockets) created below the high density warp and weft yarns allow moisture vapour to escape outwards, yet prevent wind and rain penetrating inwards. Microfibres are incredibly soft and fluid and they do not stain or fade. Even though they need greater amounts of dyestuff vivid colours can be produced. Both synthetic and natural fibres blend well and diverse range of finishing techniques can be applied to enhance the tactile qualities. The appeal of these fibres has ensured their inclusion in an increasing range of garments.

2.3 DEVELOPMENT OF STRETCH

For many years natural rubber was the only stretchable substance available, its use was limited in the garment industry and was mainly confined to corsetry and footwear. The development of rubber technology was the precursor to the synthetic alternative elastane.

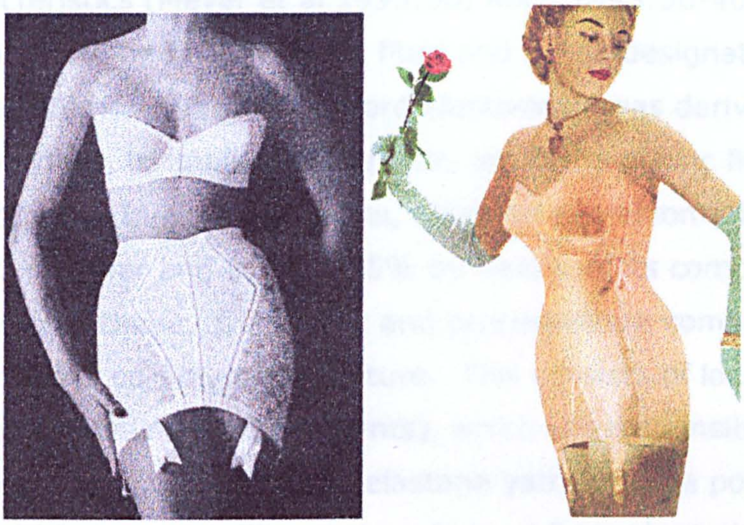
2.3.1 Rubber

The beginning of our rubber industry started with the invention of the plasticisation process in 1820 by Hancock followed by the invention of the vulcanisation process by Goodyear in 1839 (Ultee 1993:278). These inventions meant that rubber could be processed to stretch many times its own length and rapidly return to its original length when the restraining force was removed. Even after vulcanisation had been discovered, elastic threads could still only be made by cutting strips from sheets of processed rubber. However, during the 1930's a new technique was perfected for extruding liquid latex rubber, vulcanising agents and other substances, through holes in a spinneret. This process made it possible to produce very fine, round filaments in unlimited lengths.

As the use of rubber continued to grow, its disadvantages became more apparent. The filament had a tendency to discolour and sometimes even to stain other fibres it came into contact with, simply because of the vulcanising agents used. The rubber perished and degraded when exposed to oxygen, light, oils, fats and perspiration. Additionally it could not withstand prolonged exposure to elevated temperatures.

Substantial improvements in processing during the 1950's meant that the white rubber filaments were more resistant to discoloration and to existing forms of degradation. This, combined with the introduction of high-speed warp knitting machines capable of producing elastic fabrics with two-way stretch, fed the increasing demand for lightweight support garments.

Examples are the 'roll-on' constructed from a complete circle of elastic fabric, which one literally rolled on over the hips and the side-fastening girdle (see Figure 6).



a) b)

Figure 6 – a) Roll-on. Source: Vogue Paris. 1958:41 b) Side-Fastening Girdle. Source: Bond (1981:143)

The United States Rubber Company marketed its new modified rubber fibre 'Lastex' for use in hosiery, foundation garments and swimwear. Although Lastex was highly successful at the time, it had inherent problems. Not only was it heavy and hot to wear but it was prone to drying out resulting in a loss of elasticity and a short flex life. It was difficult to embed the rubber in textiles successfully, although the wrapping yarns could be dyed relatively easily, the rubber could not and was liable to 'grin through' or show. Exposure to the myriad of common factors already mentioned caused the rubber to degrade. With the unsatisfactory nature of rubber and the growing demand for form persuasive garments, the race was on to find a substitute. The production of lighter synthetic fabrics precipitated the need for finer, lighter and more durable elastic. This was not possible with rubber, as the technology had progressed as far as it could; a synthetic alternative needed to be found.

2.3.2 Lycra®

In 1937, Bayer, Rink and co-workers at the German Company Bayer Ag discovered a polyurethane-based process for producing filaments with elastic characteristics (Meyer et al 1995:58, Koch 1995:30-40). A new classification had to be found for this fibre and it was designated an elastane or elastomeric fibre. The word elastomeric was derived from elastic and polymer, to imply a man-made, synthetic plastic fibre (Gohl and Vilensky 1983:98). In chemical terms, elastane or elastomeric fibre, is a long-chain co-polymer and at least 85% by weight of its composition is segmented polyurethane. Chemistry and processes are combined to form an orientated block co-polymer structure. This consists of long, disordered, flexible molecular chains (soft segments), which are responsible for the rubber-like high stretchability of the elastane yarns and tie points (hard segments), which are crystalline regions formed from short chains and are responsible for the network of cross links (see Figure 7).

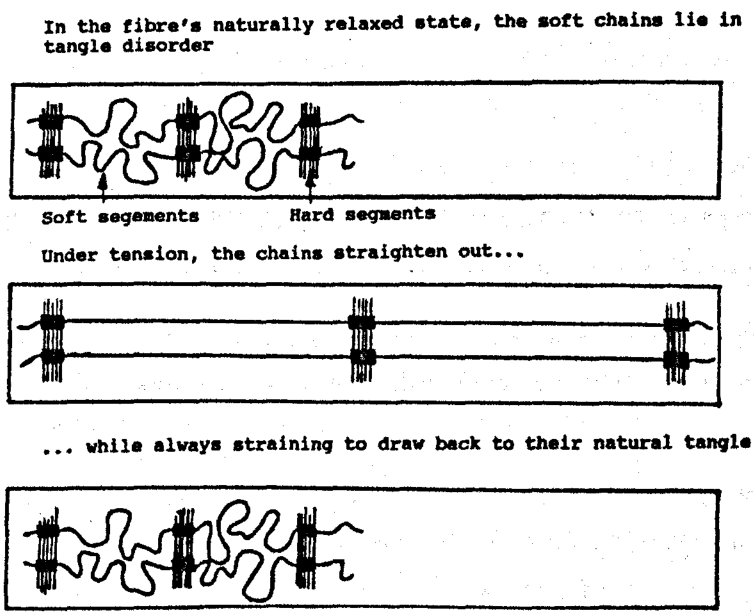


Figure 7 - Elastane Stretch and Recovery. Source: Du Pont Technical Information (1996:5)

This molecular structure endows the fibre with its built-in capacity for stretch and recovery. During deformation the stress is transferred to the molecular chains, forming soft segments which uncoil and extend with the hard segment matrix, causing the yarn to spring back to its original length when the stress is released after deformation (Koch 1995:32). It is stronger and more durable than rubber and has two or three times more restraining power, at one third of the weight. It can be extended up to seven times its own length and recover immediately, almost to its original length, when the tension is relaxed.

2.3.2.1 Elastane Production and Development

The development of this lucrative alternative to rubber was undertaken by a number of different companies, each pursuing their individual research programmes. DuPont, Toyobo, United States Rubber Company, Globe Rubber Company, and Bayer AG are highlighted here. The simultaneous development of fibre-spinning technology facilitated the viable production of these filaments with elastic properties.

Following ten years of intensive research by Snyder, Shivers and co-workers in the research division of DuPont de Nemours and Co, elastomeric fibres based on polyetherurethane were introduced to manufacturers. The product was initially known as 'T-80' and was released for trade evaluation in the foundation garment industry in early 1958, under the code name 'Fibre K'. In October 1959 it was introduced commercially using the trade name 'Lycra' in Britain. In America and Canada the fibre is referred to as spandex, the generic term for elastane or elastomeric fibres, which was created by transposing the syllables in the word expand (Gohl and Vilensky 1983:99-104). After a further three years of intensive research and evaluation Lycra (elastane) was brought into full-scale production in 1962.

By 1962 Toyobo of Japan joined DuPont in the production of spandex by the dry spinning process. Around the same time, the United States Rubber Company introduced 'Vyrene', a coarse, round monofilament elastane based on Polyesterurethane. Similarly, the Globe Rubber Company produced

'Glosspan' and 'Clearspan', which was nearly transparent. This was unusual because the elastane fibre in general was delustered and white. During 1964 Bayer Ag, in Germany brought out an elastane polyesterurethane-based yarn, which was the original version of 'Dorlastan' (Ultee 1993:282).

2.3.2.2 Elastane Structure

The basic principles for the structural requirements of elastane fibres, based on different component materials and spinning processes, are well established. Although diverse soft segment chemistries have been evaluated, it is the polyether and polyester chemistries that are most commonly manufactured. Polyether is preferred because of its various attributes and it is cheaper to produce than other elastanes with a different polymer base. Its uses are multifarious contributing to over 85% of man made elastic fibre production. The chemicals are extruded through a spinneret to produce continuous filament yarns. The filaments are of considerable length, often as much as several kilometres (Scrimshaw and Bingham 1994:3). The elastane filaments can be produced by four spinning processes - dry, wet, reaction, and melt spinning - yielding products with differing attributes (Snyder 1996:56).

The ability of elastane fibres to be thermally and hydrothermally set has a profound effect on the quality, dimensional stability and performance of the finished product (Meredith 1971:36, Bosman and Schollmeyer 1987; Koch 1995). The higher the tension and temperature, the more pronounced is the restructuring process and this affects the amount of available stretch and power, which is adjusted through the application of heat. This process is of considerable technological importance in the design and potential uses of fabric containing elastane.

2.3.2.3 Elastane Insertion

The addition of elastane fibres to all types of fabrics, natural and man-made, does not change their appearance or alter their natural look. The elastane fibre is always processed together with a companion yarn to produce the fabric; an elastic fabric never consists of 100% elastane fibre. Figures 8 and 9 illustrate elastane insertion in knitted fabrics.

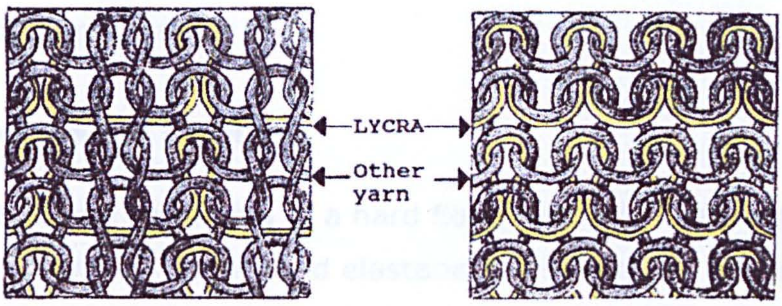


Figure 8 - Weft Knit Elastane Insertion. Source: Du Pont Technical Information (1996:10)

The companion yarn is inelastic and is referred to as a hard yarn or fibre. It is the companion yarn that gives the fabric its aesthetic appearance, as the elastane is not visible. However, the incorporation of bare elastane has both technical and design limitations as some fabric construction techniques cannot cope with highly elastic yarns. Encapsulating the elastane filament within a rigid fibre helps to control elasticity, temporarily stabilising it and improving processibility (Meridith 1971:44).

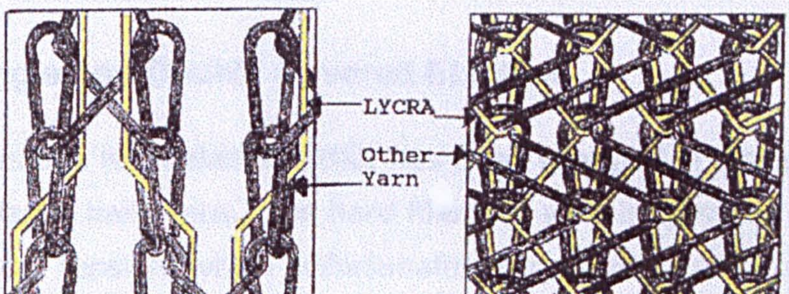


Figure 9 - Warp Knit Elastane. a) Raschel with Elastane b) Tricot with Elastane. Source: Du Pont Technical Information (1996:12)

2.3.2.4 Bare Elastane

Bare elastane refers to the naked, extruded elastane filament yarn that has not been covered in a hard fibre or yarn. Bare elastane has good dye receptivity and can be produced as an extremely fine yarn. Uncovered elastane is lighter, sheerer and suppler than covered elastane. It is utilised in garments where these characteristics are desirable, for example lingerie, form-persuasive garments and sportswear. The elimination of the covering process can reduce production costs, but makes it less stable to handle in the production process.

2.3.2.5 Core Spun Elastane

This is a structure consisting of a hard fibre, natural or man-made, which is spun around a core of tensioned elastane see Figure 10. The resultant yarn has the aesthetic appearance and handle of the sheathing fibre.

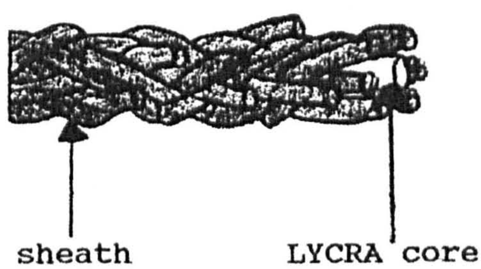


Figure 10 - Core Spun Elastane. Source: Du Pont Technical Information (1996:7)

2.3.2.6 Single and Double Covered Elastane

Covered elastane is an elastane that has been wrapped in a single or double layer of inelastic hard yarn. The hard filament yarn is spiralled round elastane under tension, which unfortunately produces a yarn that has a tendency to spiral. A second layer is usually wound in the opposite direction to stabilise the yarn. This is described as S and Z twist as shown in Figure 11. The first covering normally controls the stretch, while the second cover gives the yarn balanced torsion and a smooth appearance (Meridith 1971:45).

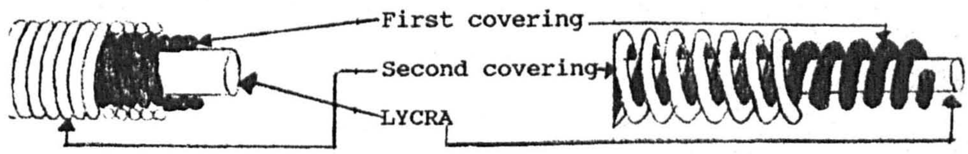


Figure 11 - S and Z Twist. Source: Du Pont Technical Information (1996:8)

2.3.2.7 Interlaced Elastane

Interlaced elastane is produced by combining a hard multi-filament yarn with tensioned elastane through a compressed jet of air. The partly covered elastane hooks onto the interlacing filament (see Figure 12). This combination is desirable where a smoother elastic yarn might slip out of place in certain constructions. Interlaced elastane has similar characteristics to other man-made fibres in terms of processing and finishing. Combining interlaced elastane with a rigid fibre helps to control the elasticity and offers better handle.

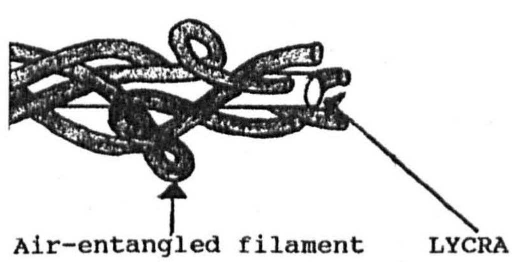


Figure 12 - Interlaced Elastane. Source: Du Pont Technical Information (1996:9)

During the manufacturing process, elastane is incorporated in the fabric under tension, which when relaxed pulls the fabric together. The inelastic companion yarn memorises the stretched yarn length and it is this companion yarn that limits the elongation of the fabric (Dupont 1996). The greige fabric, irrespective of whether it is of a woven or knit construction, is always wider than the finished fabric. The yarn undergoes a number of processes in finishing including heat-setting to stabilise it (Meredith 1971:21). The heat-setting process is one of the most important steps as this ultimately determines the stretch properties of the fabric for its final performance requirements. The subsequent process of dying and finishing then fully restores the elasticity.

2.3.2.8 Elastane Fibre Contents

The elastane fibre content is usually determined by the field of application (Mayer 1995:60) and broadly falls into the categories outlined in Figure 13. The type of fabric and its designated optimum performance for a specific end-use determines the amount and classification of elastane.

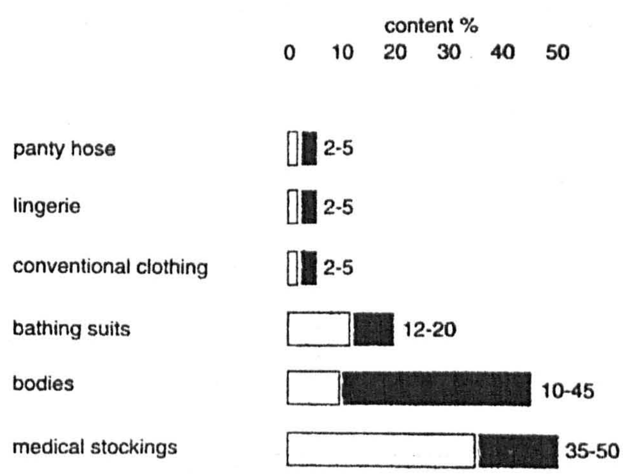


Figure 13 - Suggested Elastane Fibre Content for Different Garment Categories. Source: Meyer (1995:60)

The functionality of elastane is dependent upon the type of polymer, filament process, the count and the modulus. The count (fineness) is measured by weight/length and conveyed either in denier (grams per 9,000 metres) or the more widely used term decitex (grams per 10,000 metres).

Elastane is produced in a wide variety of decitex (from 10 decitex/deniers the finest used in sheer hosiery, to 1,680 decitex/deniers used in narrow elastic) over a range of different moduli. The modulus is a measure of the stress-strain relationship, either at predetermined loads, at elongation or throughout the entire stress-strain cycle up to a certain maximum stretch, usually well below the breaking point of the thread (Murden 1966:355). The modulus or stress-strain curve is dependent on the molecular structure and the cross-sectional area of the thread. In a stretch garment the modulus or elastane stretch strength is the ratio between the pressure exerted on the body and the force of the fabric under tension. The compression or retraction power of the elastane determines the modulus, irrespective of the percentage of elastane in a garment.

The polymer type and count of the elastane fibre, companion fibre and process can be tailored to meet specific applications. Therefore, it is the optimisation of desired characteristics for end use that determines the fabric specification. Although the elastane is invisible the benefits are that it helps to support the body, maintain body warmth, minimise fatigue and maximise mobility.

2.3.3 Alternative Stretch

Rubber and elastane insertion is not the only method of producing a stretch fabric. Stretch fabric characteristics can be developed at the fibre, yarn or fabric structure stage. Most man-made fibres can be treated by mechanical and chemical processes, which produce yarns with some degree of stretch and recovery. Not all have equally effective stretch properties or are suitable for compressive garments with body holding power for clinging and moulding properties.

Nylon and polyester have varying amounts of inherent stretch and recovery. As a consequence many twisting, sawing and heat setting techniques can be introduced to increase their stretchability. These include textured or high bulked yarns, a modified version of filament yarns, crimped yarns, high twist and false twist type yarns. In a crimp stretch yarn the fibres are neither straight nor uniform. This twisting produces a permanent change in the physical structure of the yarn. Crepe bandages are woven from crimped yarn, which forms snarls when the fibre is released in the finishing process. When included in a knitted structure a combination of yarn and fibre crimp impart a spring-like structure into knitted fabric, which facilitates rapid recovery after extension forces are released. The Haberlein Pattern Corporation was successful in producing a false twist yarn and introduced their 'Helanca' onto the market in 1947. This was a major breakthrough as the yarn in it could be stretched between three and five times its original length. The lighter the yarn the higher the stretch capacity. It had excellent recovery when released from tension, returning to its original shape. It retained its shape well and could be manufactured to various specifications for diverse applications. More recently an innovative polyester has been developed, known as polybutyleneterephthalate. It possesses excellent stretch and recovery properties (Davis 1999:58), is easy to produce and is said to 'contain without constraining'. KoSa, the Japanese Company use it to make 'ESP' (Extra Stretch Potential). Nylstar also use it in their highly successful aquawear 'Elite', as it is hydrodynamically engineered to channel water away from the body giving increased speed.

2.4 KNIT STRUCTURE

Most knit fabric structures, depending on the mode and type of knitting process, have inherent stretch in one or both directions. Knitted fabrics are constructed through the process of forming interlocking loops (stitches) with one or more yarns over a hooked needle, inter-linking the preceding and succeeding courses (Gioello 1982:57-67).

The yarn forming the loop is subjected to complex bending and twisting forces (Doyle 1953:567). The structure maintains itself in a particular three-dimensional configuration by the balancing of a system of opposite elastic reactions.

- **Course:** Horizontal rows of loops are called the **course**; these run across the fabrics from side to side (see Figure 14). In a woven construction this corresponds to the weft.

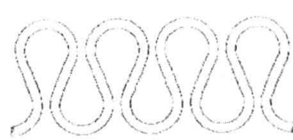


Figure 14 A Single Cource of Plain Fabric . Source: Brackenbury (1992:23)

- **Wale:** Vertical columns of loops in knitted fabrics are called the **wale** and they run the entire length of the fabric (see Figure 15). This corresponds to the warp in woven fabrics.

Figure 15 - A Single Wale of Plain Fabric. Source: Brackenbury (1992:22)

Figure 16 shows vertical and horizontal alignment of the wale and course construction.

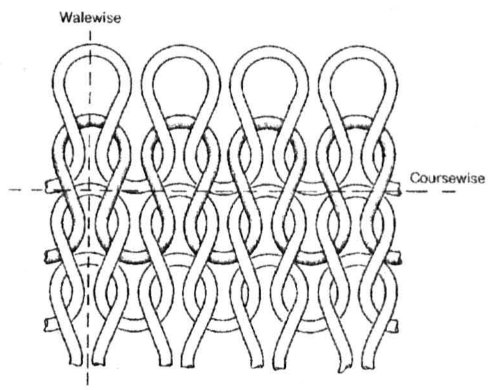


Figure 16 – Simple Interlinked Wale and Course Structure. Source: Brackenbury (1992:23)

The two basic structure classifications known as 'warp' and 'weft' are defined by the knitting technique used to construct the fabric.

2.4.1 Weft Knit Construction

Weft knit fabrics are produced by interlocking loops in the course (horizontal direction), with each course built on top of the other (see Figure 17). The loops in the course are made up of a single yarn, which is inserted at right angles to the direction in which the fabric is produced. Each loop is formed by the previous row of loops as each needle pulls the crosswise thread in succession. This construction forms knit fabrics with inherent elasticity (Scrimshaw and Bingham 1994:1-3).

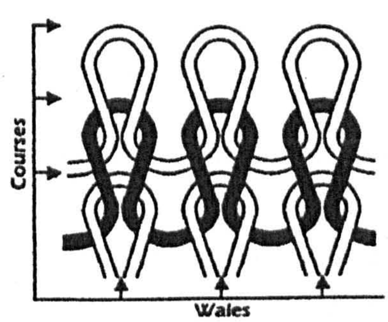


Figure 17 Simple Weft Knit Structure. Source: Scrimshaw and Bingham (1994:1)

2.4.2 Warp Knit Construction

Warp knit fabric is produced by interlocking loops in the wale (vertical) direction (see Figure 18). Each loop in a course is constructed out of single parallel yarn. All the needles in the course move up, simultaneously interlacing the previous loops. The yarn passes through guides which are positioned on a bar just above the needles. The loops are interlinked as the guide bar moves backwards and forwards and from side to side. This lateral motion is referred to as lapping. Most fabrics constructed by this method produce materials that have little or no inherent elasticity; it is the fibre content that imparts the stretch qualities. Tricot is a simple warp knit structure and is constructed using two sets of threads and two guides with each needle. The two sets of threads, one at the front and one at the back, are lapped in opposite directions across one needle space.

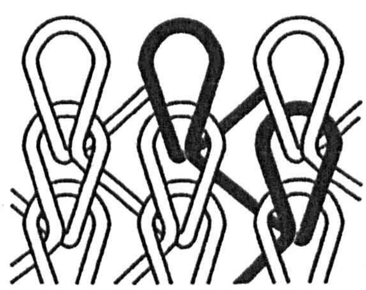


Figure 18 - Simple Warp Knitted Structure.
Source: Scrimshaw and Bingham (1994:2)

2.4.3 Weft and Warp Combined Construction

An alternative weft knitting system, which combined weft and warp knitting techniques, did not slot into the conventional categories. This construction has been described by Baesgen (1993:170-173, 1993:232-235). Bayer AG markets the fabric 'Duolastic®' produced by this method. The knitting machine was developed by Karl Mayer, Textilmaschinen GmbH. In brief, the composition of the yarn system merges both of the previous warp and weft techniques and combines the multi-yarn warp knitting techniques which run vertically with the single yarn weft knitting technique. In the warp direction covered elastane yarn forms loops together with the weft yarns which may be non-elastic or contain elastane, thus creating a balanced bi-directional stretch fabric, see Figure 19.

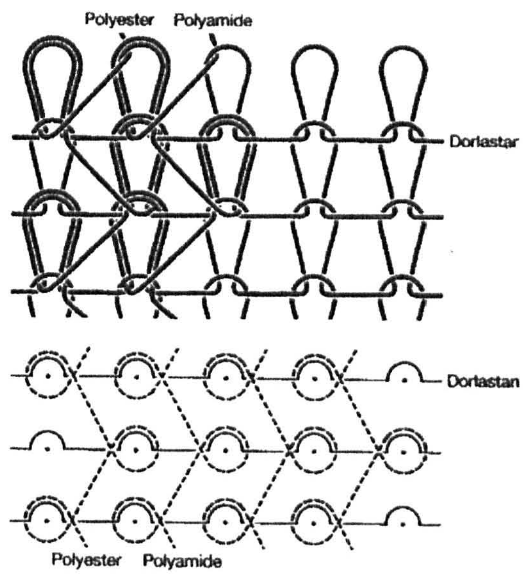


Figure 19 - Structure of Duolastic® fabric (Tricot and Weft Loops) Dorlastan® 160dtex;Polyamide 56dtex; Polyester 50dtex. Source: Baesgen

Through the use of different yarns and constructions, numerous pattern variations can be produced. It is difficult to compare with conventional construction techniques, because it is so different. However, Baesgen states that, in comparison to other stretch fabrics, Duolastic® fabrics have much better elastic recovery and lower residual elongation. It has high uniform lengthways and crossways elongation, producing lightweight fabrics with high holding force. In garment form the seam slippage resistance is good and it also has excellent run resistance, as the elastane yarn is an integral part of the loop structure.

2.4.4 Knit Stretch Fabrics

The development of stretch knit fabric technology is increasingly sophisticated. The interrelationship of fibre composition, stretch type, production process and the application of various finishing techniques all contribute towards the stretch performance characteristic. The knit construction technique in this study, whether it is a warp knit or a weft knit or whether the fibre content contains elastane or the stretch is imparted through mechanical or chemical means, is not a major concern. What is of interest is that the stretch knit fabric is constructed of a matrix of interlocking loops. The yarn forming the loop is subjected to complex bending and twisting forces. It is the way in which the structure maintains itself in a particular three-dimensional configuration in combination with the stretch distortion characteristics that makes it particularly suitable for conforming to the body.

2.5 VISUAL STRETCH CHARACTERISTICS EXPLORED

A visual appreciation of fabric stretch distortion characteristics is vital when developing an understanding of pattern geometry, to achieve an accurate fit in the process of pattern reduction and subsequent fabric stretch distortion over the contours of the body.

To promote the designer's understanding of fabric stretch characteristics from a visual perspective, a series of experiments were required. This was accomplished by recording the stretch distortion of a warp knit stretch fabric when extended by fixed increments of up to twice the sample length.

The following test methods have been designed to give a visual appreciation of the relationship between the fabric geometry and fabric stretch curvilinear distortion. This knowledge is used subjectively to enhance the fit quality when evaluating a garment/pattern as integrated geometrical shapes.

2.5.1 Uniaxial Linear Distortion

If a garment pattern is perceived as being constructed from an array of geometric shapes, areas that are not predominantly rectangular need to be isolated. Areas vulnerable to the greatest deformity can be defined according to the predominant geometric shape. Investigation of the visual stretch characteristics of sample shapes, such as rectangles, trapezoids and triangles, will provide data for predicting the stretch characteristics of these areas. The fabric sample (Table 1) for this experiment was a warp knit stretch fabric, one of a number chosen for this research; the others are detailed later in Section 2.7.1.2.

Code	Quality	Description	Polyester %	Elastane %	Colour
C	21132	32gg 260g Animalmax	88	12	White NR4888

Table 1- Sample Fabric C Characteristics

2.5.2 Aim and Objectives

To observe and record the effect of uniaxial incremental stretch extension of stretch fabric using a digital scanner to promote an understanding of stretch curvilinear distortion for pattern production and garment fit evaluation.

To assist in visualising the fabric stretch characteristics of rectangles in both course and wale direction whilst allowing and preventing waisting.

To visualise the effect of stretch extension on triangles of differing widths by recording and interpreting the effects of curvilinear distortion brought about by the geometry of stretch fabric for transposition to the geometry of the stretch block pattern profile.

2.5.3 Method

2.5.3.1 Fabric sample - Rectangular

The fabric to be observed was a 20cm square marked with a 4cm grid. *Seams measuring 2cm formed slots on all four sides into which 4mm* diameter metal rods could be inserted. The horizontal rods applied the tension to the fabric and the vertical rods, when inserted, prevented waisting.

2.5.3.2 Fabric sample - Triangular

Similar tests were carried out using triangles to observe the effect that varying the angle had on visual distortion. The samples had standard lengths of 20cm and widths of 5cm to 30cm in 5cm increments. A seam at the base and at the apex of the triangle measuring 2cm formed a slot into which a metal rod 4mm in diameter was inserted. The test was not concerned with either the fabric orientation or waisting prevention.

2.5.3.3 Test rig

A sheet of 15mm thick white melamine chipboard was marked and drilled to accept four retaining screws as illustrated by the uniaxial test rig in Figure 20. The bottom retaining screws were repositioned after each test to increase the amount of stretch applied by increasing the extended length in 12mm steps. O corresponds to zero stretch and 7 to maximum stretch.

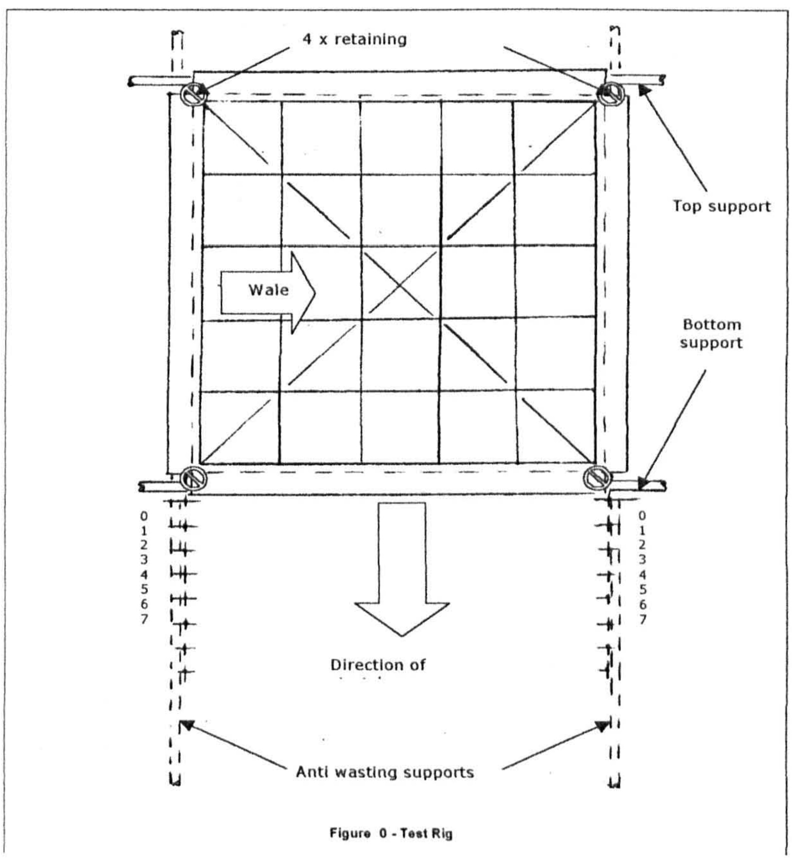


Figure 20 – Uniaxial Test Rig

2.5.4 Rectangular Tests and Procedure

Four separate tests were conducted:

Test CW - Course, allow waisting

Test WW - Wale, allow waisting

Test C - Course, prevent waisting

Test W - Wale, prevent waisting

Test CW - Course, allow waisting

2.5.4.1 Procedure

1. Slide top support rod into position through top slot
2. Fit bottom support screws in position 0
3. Slide bottom support rod into position through bottom slot
4. Stretch fabric and hold bottom rod in position by the appropriate retaining screws
5. Scan the distorted fabric
6. Remove fabric and allow to recover

Repeat the above for retaining screws in positions 1 to 7

Test WW - Wale, allow waisting

Repeat Test C with the fabric orientated in the wale direction

Test C - Course, prevent waisting

Slide the two anti-wasting rods into the side tubes and repeat Test CW

Test W - Wale, prevent waisting

Slide the two anti-wasting rods into the side tubes and repeat Test WW.

2.5.5 Triangular Test

Object

To investigate how geometry effects the stretch distribution curves of triangular fabric samples when stretched to 100% of their original length.

2.5.5.1 Preparation

All test pieces were cut with the apex in the wale direction.

They had a length of 20cm and base widths of 5cm, 10cm, 15cm, 20cm, 25cm and 30cm.

Slots were formed at the base and apex for the support bar.

The fabric was prepared with 1cm gridlines.

2.5.5.2 Procedure

The test rig illustrated in Figure 20 was used to support and stretch the test samples as follows.

1. Select the test sample and insert top support rod into position through slot at triangle base
2. Insert bottom support rod into position through the slot at triangle apex
3. Stretch fabric test piece by 1cm and hold bottom rod in position
4. Take readings at the extended position along the vertical centreline of the 20 gridlines.
5. Repeat 3 and 4 until 20x1cm incremental readings have been taken.
6. Digitally scan the distortion at 100% stretch.

Repeat the above for the 10cm, 15cm, 20cm, 25cm and 30cm samples.

The digital scans of the visual distortion and tabulated recordings are included in Appendices A and B for the rectangular and triangular samples respectively, together with plots of extension/percentage stretch a correlation curves between samples.

2.5.6 Results

2.5.6.1 Rectangular

When the rectangular fabric that was subjected to stretch in both the course and wale directions with the sides either supported or unsupported, the general conclusion was that the fabric deformation was linear throughout the 100% extension range (see Figure 21 and Appendix 1). The waisting allowed by the unsupported fabric, in that particular geometric shape had little effect on the general visual impression. However, the waisting is of significance for the pattern profile geometry.

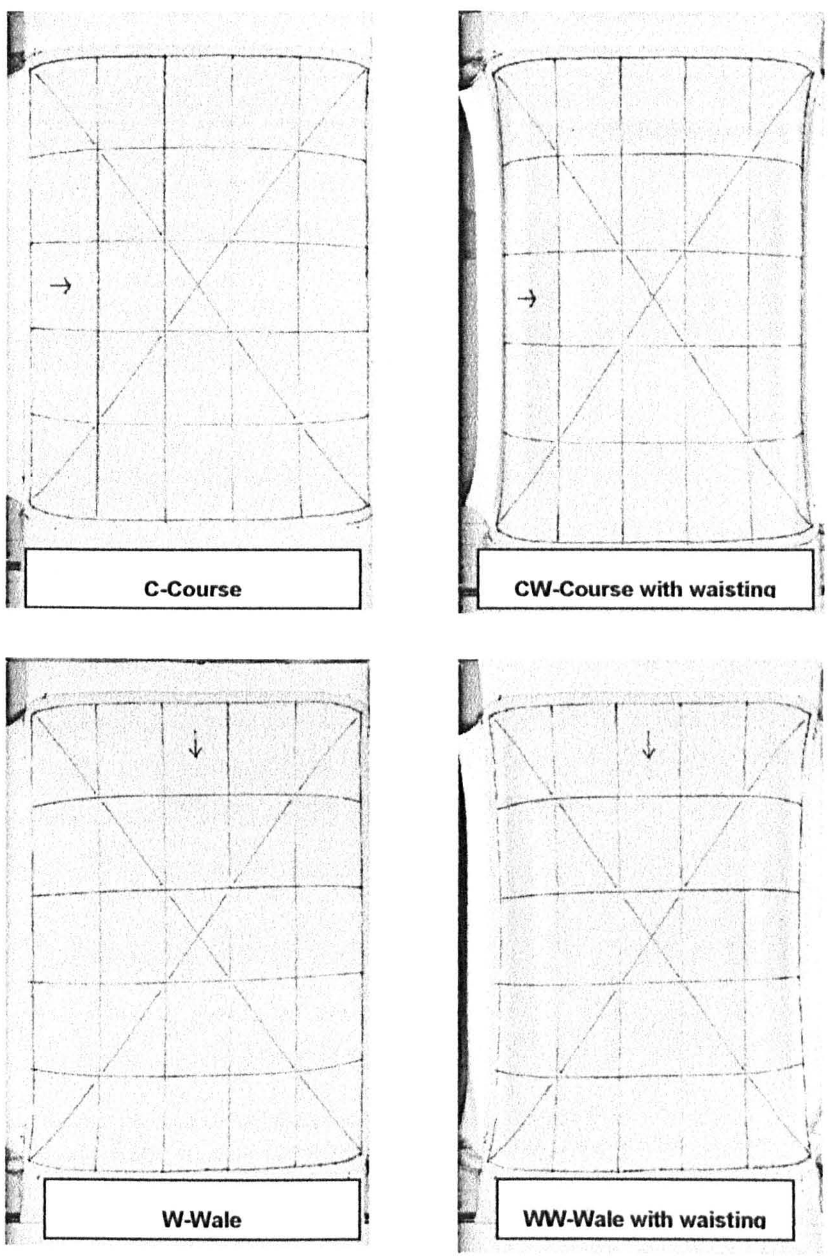


Figure 21 Supported and Unsupported Course and Wale Uniaxial Linear Distortion

2.5.6.2 Triangular

The conclusion reached regarding the visual distortion of the triangular samples was that the fabric deformation along the centre grid lines of the test samples was non-linear but was coincidental between the sample range throughout 100% extension, irrespective of the angles of the sample size.

The shape of the fabric will effect the way in which it deforms. In Figure 22 it can be observed that as unilateral tension is applied to a triangular shape, it will deform in relation to the lateral forces of the fabric construction, which decrease towards the apex of the triangle. This brings about a non-linear stretch characteristic.

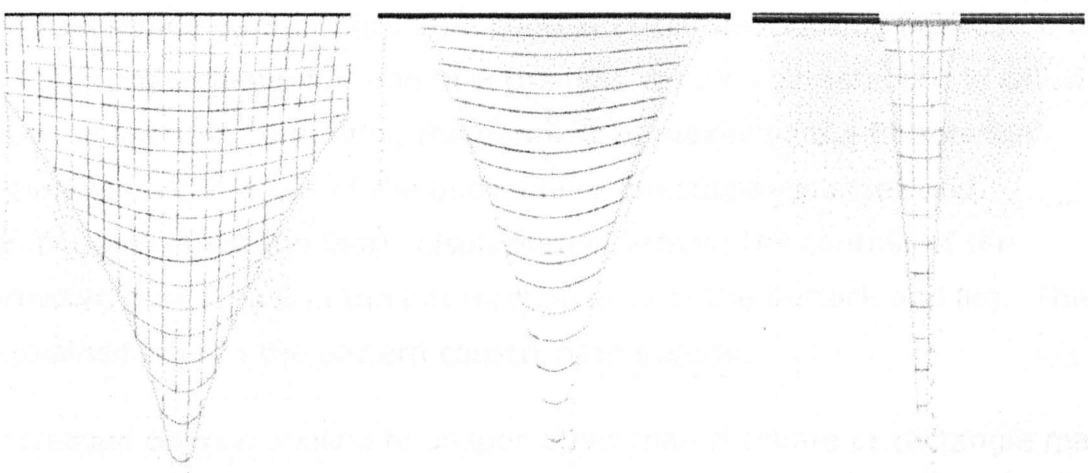


Figure 22 - Triangular Shape Deformation

2.5.7 Conclusion

If an increasing tension were applied to a single strand of an elastic fibre, the elongation to breaking point would be close to linear. When uniaxially applying tension to a rectangle of fabric, irrespective of the chosen method of applying force, the stretch characteristic observed at the centre of the fabric will be linear.

When observing the deformation of a rectangle of stretch knit fabric, the lateral forces brought about through this tension will cause the fabric to waist at the edges. However, the extent of waisting becomes less visually apparent with increasing fabric width. The effect of this waisting on the linear stretch although visually minimal, demonstrates the effect of the bias stretch characteristic in action. This feature has great significance for understanding garment fit in the context of the relationship between the pattern profile geometry and how the bias stretch characteristic is called upon to assist in contouring the garment to maximise the fit potential. Examples are in areas of the body where directional changes and protrusions effect the fabric displacement around the contour of the armscye bust area and the intersecting area of the buttock and leg. This is explained later in the pattern construction section.

Increased tension applied to shapes other than a square or rectangle may not appear to differ visually across the fabric sample centre gridline over a range of angles, but the applied force for a given fabric extension must reduce with the angle of the triangle. The interpretation of the stretch characteristics of sample shapes, such as rectangles, trapezoids and triangles is used subjectively to enhance the fit quality of the pattern profile when evaluating a garment/pattern as integrated geometrical shapes.

This also highlighted an area requiring further investigation, which was the relationship between the applied force and fabric extension.

2.6 REVIEW OF STRETCH EXTENSION TEST METHODS

Stretch fabrics are produced in a broad range of fibre content and weights with a stretch extension capacity for a variety of applications. During the manufacture of stretch fabrics it is difficult to consistently produce fabric to a specific stretch extension, as small variations within production tolerance impact on the finished fabric. In addition, manufacturers do not offer a stretch extension classification system specifically for stretch garment pattern design.

2.6.1 Stretch Theory

Understanding stretch theory is essential to quantifying the degree of fabric stretch extension as an intrinsic part of the stretch block pattern reduction process. Stretch extension considers the relationship between the relaxed and extended lengths of a fabric sample.

An example would be a strip of fabric having a relaxed length of L and a unit width. When a unit force is applied along its length the material will stretch to an extended length Ls.

Subtracting the original relaxed length from the extended length will give the amount by which the sample has stretched δL. The degree of stretch S expresses the stretch length as a percentage of the original length.

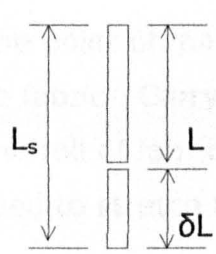
The calculation for the degree of stretch extension is defined

L = relaxed length

δL = amount of stretch

L_s = extended length

S = degree of stretch



The extended length in either the wale, course or bias direction is the sum of the relaxed length and the amount of stretch.

extended length $L_s = L + \delta L$

Stretch degree is expressed as an amount of stretch per relaxed length.

$$\text{Stretch degree } S = \frac{\delta L}{L} * 100\%$$

2.6.2 Hand Stretch

The review of existing methods highlights the need for the designer and pattern technologist to have a method of quantifying stretch extension simply and objectively.

To quantify the degree of stretch some technical publications and manufacturers recommend the *hand stretch* test method, which is generally agreed to mean '*the useful limit of extension*'. Theoretically it is the point at which the stretched fabric has reached its maximum extension without deforming the hard yarns or fibres. The test method takes a 3" (7.5cm) width of fabric on which benchmarks are drawn 10" (25cm) apart. The fabric is then gripped on either side of the benchmarks with the thumbs positioned on the top. The sample is then extended until a reasonable resistance to stretching is felt, the degree of extension is then measured on a ruler (Murden 1966:356).

Murden suggests that although it is not easy, with practice, reproducible results are obtainable even between different operators. However, he does have reservations on the sample width of 3" and suggests that for female operators a 1½" (3.7cm) sample width would be more suitable, particularly for strong elastic fabric, as the narrower width would extend more easily. This would assist the operator to sense the point of maximum resistance instead of concentrating on extending the fabric. Carrying out this test method on wide sample pieces or even the roll of fabric is inappropriate, as the focus is then on the sheer effort needed to stretch the fabric, which defeats the object of the exercise.

Variations of the hand stretch method can be employed whereby samples of fabric of varying widths greater than 3" (7.5cm) and different lengths (Haggar 1980:244) are pulled until a reasonable resistance to stretch is felt, or until they are visually unacceptable. Depending on the degree of stretch recorded the sample is then categorised.

In a section of her book Armstrong (1995:471) outlined a method for assessing the degree of stretch extension. Her stretch gauge rule has the degree of stretch marked off in percentages (see Figure 23). For the test she suggests using a rule stuck to a piece of card so that this can be taken easily to the site of the fabric. The end section of the fabric roll is folded lengthwise and marked with pins five inches apart. The fabric is held firmly and stretched to the point just before distortion (parallel folds) is reached and then measured. This is then repeated for the crosswise grain.

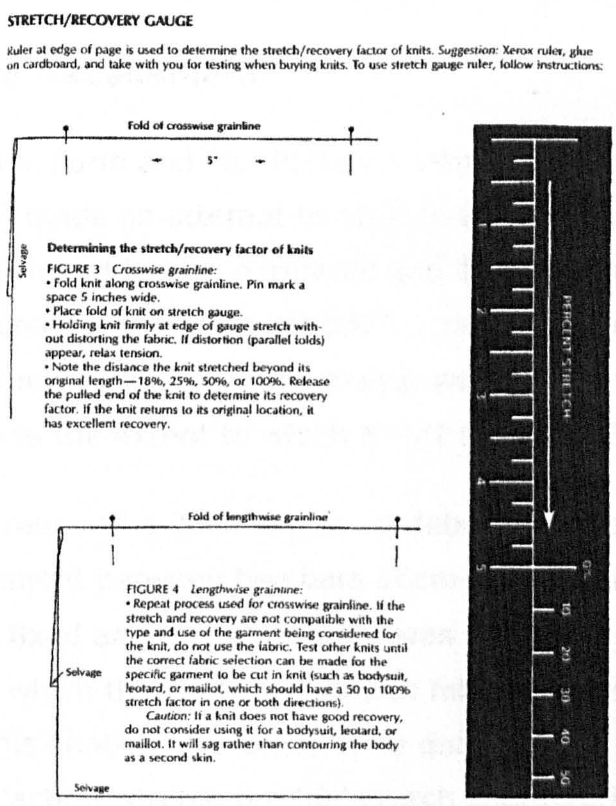


Figure 23 - Stretch Measuring. Source: Armstrong (1995:471)

Because the tests outlined require the individual to assess the effort exerted before resistance to stretch is reached or the point at which a fabric becomes visually stressed, the results obtained will vary. Although with experience it is possible to assess the degree of stretch extension, it nonetheless relies heavily upon subjective judgement.

An important variable, the position of the hands on the fabric sample, is not usually stated. This is a serious omission as hand placement has a radical bearing on the resistance to stretch experienced.

The value of using of a small fabric sample without any visual indication of the fabric stretch characteristics when transposing visual stretch in relation to the larger finished garment is questionable. When scaling up from small sample sizes to a finished garment the suitability of visual stretch assessment without visualising the fabric stretch deformation is also questionable.

2.6.3 Objective Assessment

In her book, 'Fabric Form and Flat Pattern Cutting' published in 1996, Aldrich (1996:27) made an attempt to objectively assess fabric extension. This was for fashion and leisure garments and it stated that working with high levels of stretch in swimwear ranges " ... requires special skills and calculations". A method of assessing stretch was recorded whereby fabric was stretched up to the extent to which it was still visually acceptable.

The test method required a 20cm square of fabric of which 2cm at each end is used for attachment between two bars 16cm apart as seen in Figure 24. The first bar was fixed and the second bar was moved by 0.5cm increments until the point at which the extended stretch fabric became visually unacceptable. This enabled the fabric to be quantified in terms of a horizontal visual 'action' stretch on the 'stretch characteristic scale', which ranged from low to high. A 'visual stretch scale' was also outlined in her article.

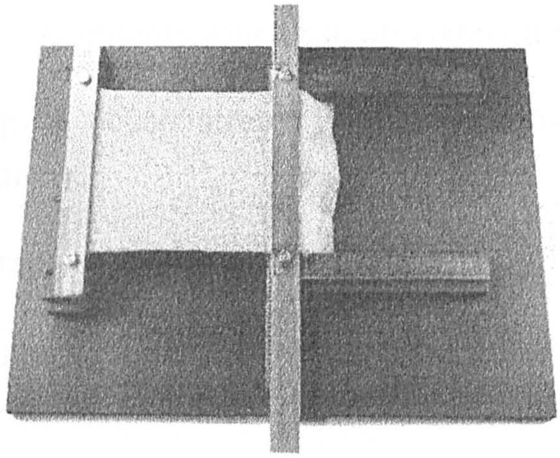


Figure 24 – Aldrich Test Rig. Source: Aldrich (1996:27)

For ease of clarity the two scales have been combined into a single table showing stretch characteristic and visual stretch scale (see Figure 25)

Holes	**0**	**1-2**	**3-4**	**5-6**	**7+**
Extension cm	0	0.5-1.0	1.5-2.0	2.5-3.0	3.5+
Percentage stretch	0	3.0-6.0	9.5-12.5	15.5-19.5	22.0+
Stretch Characteristic Scale	Low	Low-med	Med	Med-high	High
Visual Stretch Scale	5	4	3	2	1

Figure 25 – Aldrich Stretch Characteristic and Visual Stretch Scale. Source: Adapted from Aldrich (1996:27)

As a worked example, with the fabric sample relaxed length of 16cm and an extension of 2cm, corresponding to hole 4, the percentage stretch can be calculated as follows:

$$\text{Percentage stretch} = \left(\frac{\text{Extension}}{\text{Original length}}\right) * 100\%$$

$$= \frac{2}{16} * 100\%$$

$$= 12.5\%$$

Besides measuring the maximum stretch horizontally and vertically Aldrich states four other measurements which can be taken on the equipment.

1. The Horizontal visual 'action' stretch (visually acceptable stretch when the body is in action).
2. The vertical stretch.
3. The decrease in measurement of the fabric vertically, when the fabric is stretched horizontally.
4. The amount of recovery after the fabric has been stretched.

The conclusion Aldrich reached was that although the instrument measured the maximum fabric stretch horizontally and vertically:

> ...these practical amounts are of little use if the fabric appears visually unpleasant at high-stretch or near the stretch limits of the fabric. The basic pattern cutting shape has to be based on a basic 'visual stretch' measurement. On body fitting garments or other garments, the designer has to decide the amount of stretch that is visually acceptable when the body is inactive and then has to cut the garment pattern accordingly. This is the 'visual stretch' that is recorded on the measurement scale. (Aldrich 1996:27)

Aldrich utilised a test rig as opposed to a free hand method, thus reducing the margin of error caused by different hand placements. However, the results are still inconsistent, as interpretations drawn are ultimately individual conclusions. Her method made no attempt to analyse the force/extension characteristics. The classification of stretch outlined in the 'stretch characteristics scale' using categories high through low in combination with the 'visual stretch scale' is a good starting point, although it might have been more appropriate to use 0 for zero extension and 4 for 22% extension.

The test rig was not a device that was readily available and, although it gave some useful results, it would not be suitable for quickly and simply assessing fabric stretch characteristics. In the context of stretch performancewear the method has limited practical application because the forces involved were not quantified and results are likely to be inconsistent.

2.6.4 Mechanical Stretch

Determining degree of stretch extension by mechanical means can be frustrating, as there appear to be as many approaches as there are sample fabrics. Most manufacturers tend to state a single averaged course/wale stretch figure, which is inadequate for stretch pattern design. Although some manufacturers do state the different degree of stretch for both the course and wale direction, they are usually attributed to a range of fabrics. This can be misleading as it is not generally stated that the degree of stretch is obtained by applying differing loads to the individual fabrics (Ziegert and Keil 1988:56).

2.6.5 Mechanical Approximation of Hand Stretch

There have been attempts to replicate the hand stretch test mechanically. Murden (1966:356) described one theory suggesting that a good approximation of the hand stretch could be achieved by taking a 3 inch (7.5cm) width of fabric and subjecting it to a load equivalent of 5lb per inch (1kg/cm). This was based on a range of fabrics that were extended by hand and found to have this loading at the stretch point. However, equating it with the hand stretch method led to some misunderstandings in the interpretation of the test. Provided that it is fully appreciated that the fabric extension is the elongation at 5lb (2.27kg) per inch (2.54cm) of width and not the *'limit of useful extension'* then confusion should not arise.

2.6.6 Hanger Load Test

Ziegert and Keil (1988:56) developed a hanger load test method of determining stretch fabric extension for a contoured pattern design system. The method was similar to the standard test method for "Stretch Properties of Knitted Fabrics Having Low Power." (ASTM-D2594:1982) Their adaptation of the ASTM hanger load test method (see Figure 26) was used to calculate the degree of extension in both the wale and the course of a number of different fabrics.

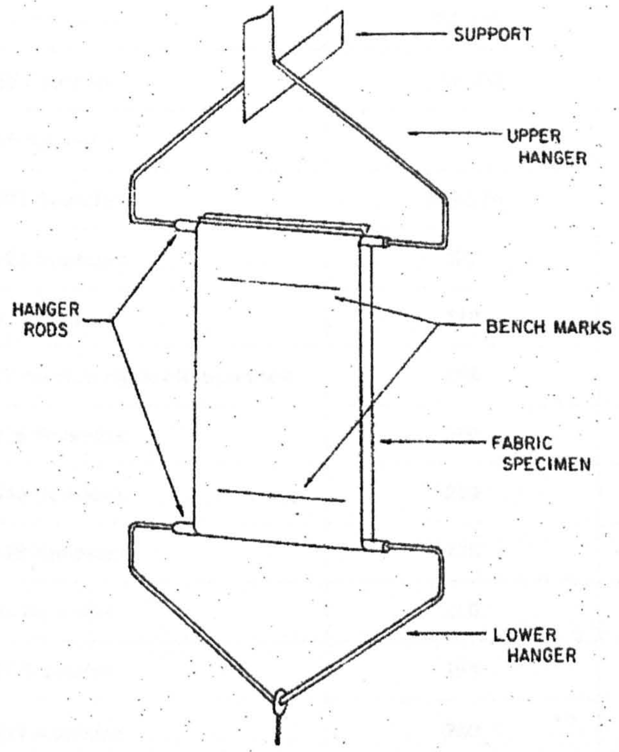


Figure 26 - Hanger Load Test Assembly. Source: Ziegert and Keil (1988:375)

Fourteen knit fabrics samples each containing different degrees of elastane were tested. The sample, a single layer of fabric, measured 40cm (15¾") long and 20cm (7⅞") wide with a hem of 3.5cm (1⅜") stitched across each end to accommodate the hanger rods. Benchmarks 10cm (3$^{15}/_{16}$") from the centre of each sample formed the measurement unit of 20cm (7⅞") by 20cm (7⅞"). A 500g load was applied to each fabric sample for 30 minutes. The rationale for the test unit size was that it related closely to one-quarter human body dimension garments made with elastomers. The hanger load test results (see Figure 27) clearly demonstrated that there was no correlation between the degree stretch and the degree of elastane fibre present in the fabric. They concluded that the elastane content is no indication of stretch characteristics.

Fabric	% Nylon/Spandex fiber content	Wale stretch	Course stretch
1	85 Nylon/15 Spandex	210-250	50-70
2	84 Nylon/16 Spandex	200-230	50-70
3	85 Nylon/15 Spandex	210-260	60-80
4	83 Nylon/15 Spandex		
5	77 Antron/23 Spandex	195-235	95-115
6	82 Antron/23 Spandex	170	85
7	81 Antron/19 Spandex	170	120
8	53 Antron/7 Stretch Nylon/40 Spandex	215	115
9	84 Antron/16 Spandex	250	80
10	51 Antron/49 Spandex	220	120
11	72 Antron/28 Spandex	235	95
12	70 Nylon/30 Spandex	200	200
13	80 Nylon/20 Spandex	195	130
14	81 Antron/19 Spandex	260	150

Figure 27 - Elastane Content /Degree of Stretch Comparison. Source: Ziegert and Keil (1988: 55)

2.6.7 BS 4952:1992

The British Standard (BS 4952:1992) 'Test Methods for Elastic Fabrics' defines elastic fabrics as those, which incorporate elastomeric threads. There are a number of specific tests to be carried out on narrow or wide elastic fabric of a woven, warp or weft knit construction. All samples are subject to specific pre test conditioning. The fabric samples can be either straight which are clamped between metal jaws or looped over two metal bars of circular cross section. The specimens are then ready to be stretched. The apparatus must be capable of cycling between zero extension and, either a predetermined force or a predetermined extension. It must also be capable of maintaining a specimen either under a constant tension or at a constant elongation. A number of tests are detailed and include methods for: fatiguing or ageing specimens; determining extensions at a specific force, modulus, tension decay, residual extension, fatigue set, elastomeric thread break and runback (BS 4952:1992). None of the methods classify stretch extension specifically for stretch garment pattern construction requirements. The stretch extension percentage is of little value for stretch garment pattern design if the specific loading is not stated.

2.6.8 ASTM Designation:D1775-1994

The ASTM Designation: D1775-1994 'Standard Test Method for Tension and Elongation of Wide Elastic Fabrics (Constant-Rate-of-Load Type Tensile Testing Machine)' outlines similar test methods to the BS 4952:1992. However, although a broad range of tests is referred to, yet again not one is relevant to classifying specific stretch extension for pattern design.

2.6.9 ASTM Designation:D2594-1982

The ASTM Designation: D2594-1982 'Standard Test Method for Stretch Properties of Knitted Fabrics Having Low Power' employs a hanger load assembly with a narrow tube of fabric. All samples are subject to specific pre test conditioning. The standard test requires five fabric samples cut from both the wale and course directions of each fabric. Again the stretch force does not pertain to the designer.

2.6.10 Uniform Radial Force Tester

Other types of mechanical devices are available for measuring stretch fabrics biaxially. A device of particular interest is the Uniform Radial Force Tester (URFT) described by Hassenboehler, Jr (1975). The tester has a circular jaw which is expanded by an arrangement of pulleys, pins and cables (see Figure 28). A circular fabric sample was pressed onto a circular pin frame jaw. Each pin could be independently rotated by means of a pulley connected to a force equalising system. Averaged biaxial force/strain curves were obtained for a number of fabrics with differing bi-directional stretch. It was concluded that biaxial extension and recovery behaviour at given force levels on the URFT could be used to define the limiting stretch parameters considered to be 'comfortable' for a given fabric. It was suggested that this would be a useful aid when designing garments for specific purposes.

Mechanically measuring fabric extension biaxially is an interesting concept. Although the fabric is extended simultaneously in all directions, it was felt that the device could not accurately replicate the deformation characteristics of stretch fabric when contoured to the body.

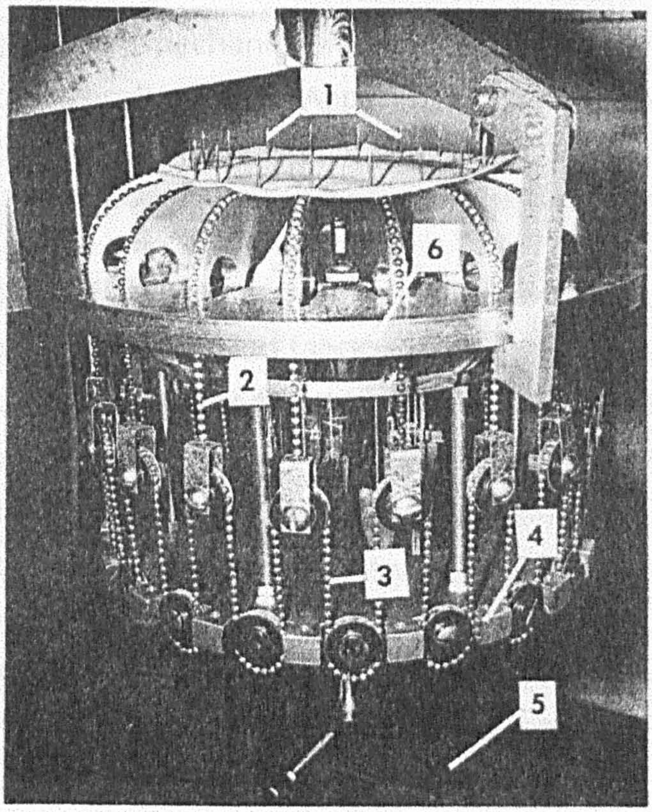


Figure 28 - Uniform Radial Force Tester Showing Arrangement of Pulleys, Pins and cables. Source: Hassenboehler (1975:21)

2.7 EXPLORATORY MECHANICAL STRETCH TESTING

There are many scientific methods for testing stretch characteristics, a few of which have already been outlined. These experiments, both manual and mechanical, are often difficult for the designer to recreate: they may not have been devised with a prior knowledge of designing garment patterns for stretch fabrics and as such the result can be incompatible with stretch garment pattern design requirements. The research has highlighted that there are numerous variations on the sample width, length and forces to quantify the degree of stretch extension which was extremely confusing. Therefore, exploratory mechanical force extension testing was undertaken using the Instron Tensile Testing Apparatus to try to identify the forces involved in stretch fabric extension in the course, wale and bias in the typical working range outlined by Aldrich in Section 2.6.3.

Because of a lack of consensus over sample sizes it was important to understand the rationale behind fabric sample sizes prior to defining the sample size to be implemented in the exploratory mechanical stretch testing. In their research Ziegert and Keil (1988:56) used a measurement unit of 20cm by 20cm with a 500g load. The rationale for the test unit size was that it related closely to one-quarter human body dimension of garments made with elastomers. However, Murden (1966:356) suggested that a good approximation of the hand stretch could be achieved mechanically by taking a measurement unit of 7.5cm wide by 25cm long with a load approximating 1kg/cm. In this confusion an understanding of fabric stretch extension characteristics was sought.

Therefore, prior to the Instron testing a hanger load test was undertaken to determine the degree of fabric stretch extension when using different widths but retaining the same measurement unit length and load.

The method and test procedure follows that outlined in sections 2.8.2 and 2.8.3 and the fabric was a warp knit sample C detailed in section 2.7.1.2.

The stretch fabric samples varied in width between 5-20cm at 5cm increments and a relaxed length of 10cm. A 10cm length was chosen because it makes measurement of percentage stretch a straightforward procedure.

The use of a loading of 1Kg was a starting point because it was expected that the Instron would suggest the most suitable load for the designated sample size.

The test results in Table 2 and Figure 29 have shown an asymptotic relationship between sample width and extension. The narrower the sample width becomes the greater the fabric extension for a given load.

Sample width (mm)	Extension (%)
5	115
10	65
15	45
20	35

Table 2- Fabric Sample Width and Extension

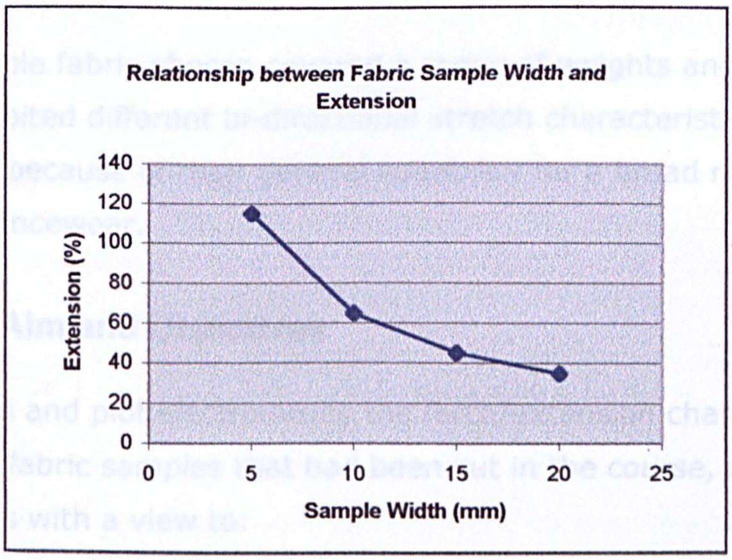


Figure29 - Sample Width / Extension Curve

The results demonstrated that narrower widths were preferable, as a 5cm width was easier to stretch than a 20cm width. The 5cm width is more appropriate for the clamping system used by the Instron tensile testing machine and also for practical considerations of cutting and making up.

The results also contributed further to the understanding of fabric stretch characteristics; the larger the fabric area the greater the force needed to deform the fabric and this is significant when analysing the fit quality relationship to the pattern geometry.

However, although the stretch fabric measurement unit had been decided, this was only the first step. The optimum force extension load needed to be ascertained using the Instron tensile testing machine before a meaningful test could be developed specifically for the designer to record the degree of fabric stretch extension as part of a pattern reduction process.

2.7.1 Instron Force/Extension Testing

The Instron tensile testing machine is used extensively to electronically calculate the extensibility a variety sample materials. The British Standard (BS 4952:1992) highlights a number of specific tests for stretch fabric not one of which is suited to garment pattern design for stretch fabric.

The sample fabric chosen covered a range of weights and elastane content and exhibited different bi-directional stretch characteristics. Fabrics were selected because of their general suitability for a broad range of stretch performancewear.

2.7.1.1 Aim and Objectives

To record and plot electronically the force/extension characteristics for a range of fabric samples that had been cut in the course, wale and bias directions with a view to:

- Analysing the effect that fabric orientation has on the load/extension curve of a given sample.

- Comparing different samples for a given fabric orientation.
- Identifying typical working ranges for the sample fabrics.
- Suggesting a loading for a fixed load test.

2.7.1.2 Method

The fabric samples coded A, B, C and D covering a range of weights and elastane contents detailed in Table 3 were selected. Fabric Sample E was not available for this test but was subsequently used.

Code	Quality	Description	Polyester %	Elastane %	Colour
A	21649	32gg 210g Coolmax/Lycra	84	16	White NR5079
B	21132	32gg 260g Animalmax	88	12	White SDI 10014
C	21132	32gg 260g Animalmax	88	12	White NR4888
D	22203	56gg 220g Coomax/T902 Triskin	80	20	White SDI 10515
E	21130	32gg 180g Coolmax/Lycra	84	16	White SDI 15243

Table 3 – Fabric Sample Characteristics

Samples of the four fabrics (A-D) were cut in the course, wale and bias (C, W and B) direction, with three sets of each orientation (1-3), making a total of thirty-six samples. Table 4 illustrates the three-digit convention that was used for fabric identification whereby Fabric A, Sample 1, Orientation C was recorded as Sample A1C.

Fabric (A-D)	Sample (1-3)	Orientation (C, W, B)
A	1	C

Table 4 - Fabric Identification convention

The test samples had a width of 5cm and were benchmarked with 2 parallel lines placed 10cm apart. All samples were subject to specific pre-test conditioning. Following the standard Instron testing procedure the fabric samples were clamped between the metal jaws taking care to remove excess slack material. The specimens were then ready to be stretched.

The Instron was set up for a simple non-cyclic test. The sample was loaded until an extension of 100% was reached. The force required was recorded at 1mm intervals for each loading. The stretch/loading characteristics were recorded using the standard Instron program. The data was then imported into a spreadsheet allowing ease of analysis.

2.7.1.3 Results

For clarity all curves have been drawn to a common scale.

2.7.1.3.1 Fabric sample orientation

The force stretch curves for samples A1, A2 and A3 and an average of sample A are illustrated in the composite Figure 30. Samples B, C and D are characteristically similar (see Appendix C).

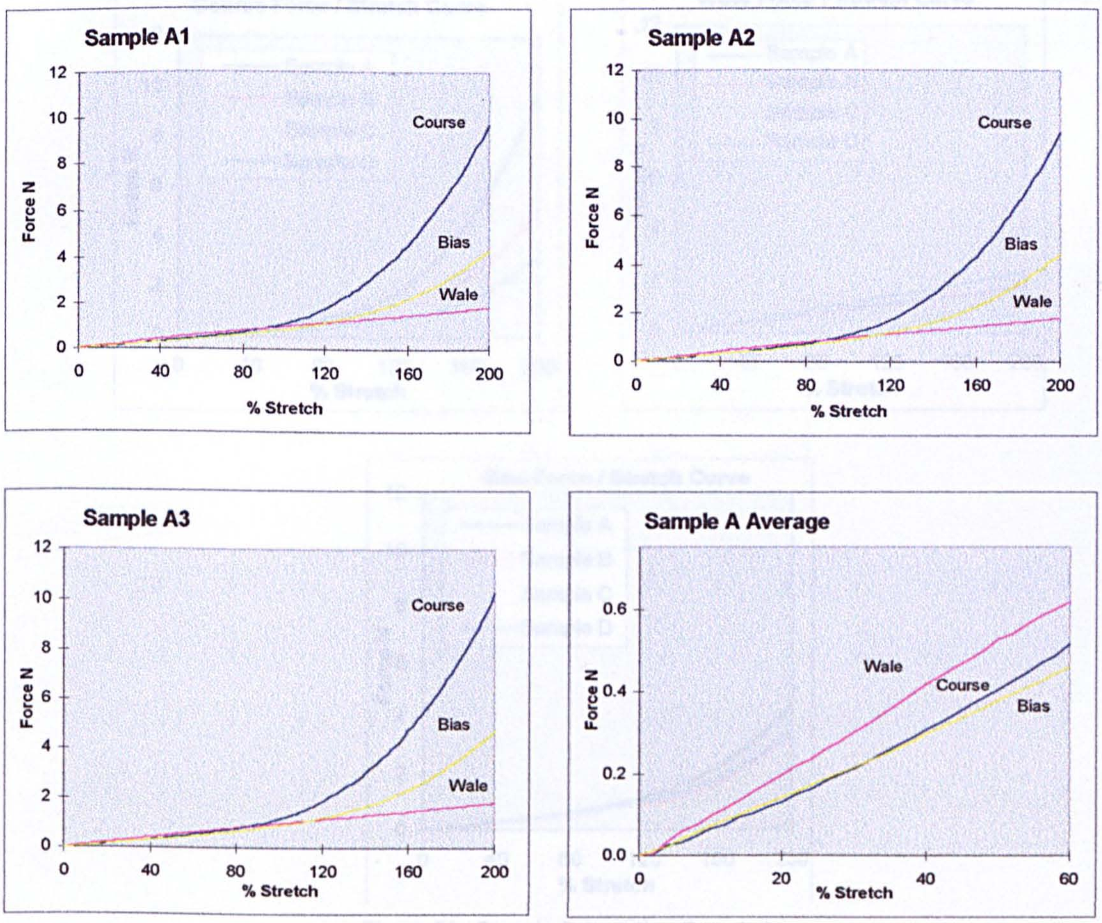


Figure 30 – Force/ Stretch Curve

There is a marked difference in the extensibility between fabric orientations for a given sample. At the higher levels of stretch the general indication is that the wale offers the least resistance to stretch and the course the greatest. However for lower values of stretch, the reverse (the course offering the least resistance) is true which is more representative of the stretch extension working range of stretch garments. This will be discussed later.

2.7.1.3.2 Fabric sample correlation

Figure 31 shows the correlation between samples A to D for the course, wale and bias orientations respectively. For a given orientation there is a good correlation between samples, suggesting that fabric behaviour could be consistent within a required working range. The wale force/stretch curves, at first sight, again suggest that this orientation offers the least resistance to stretch.

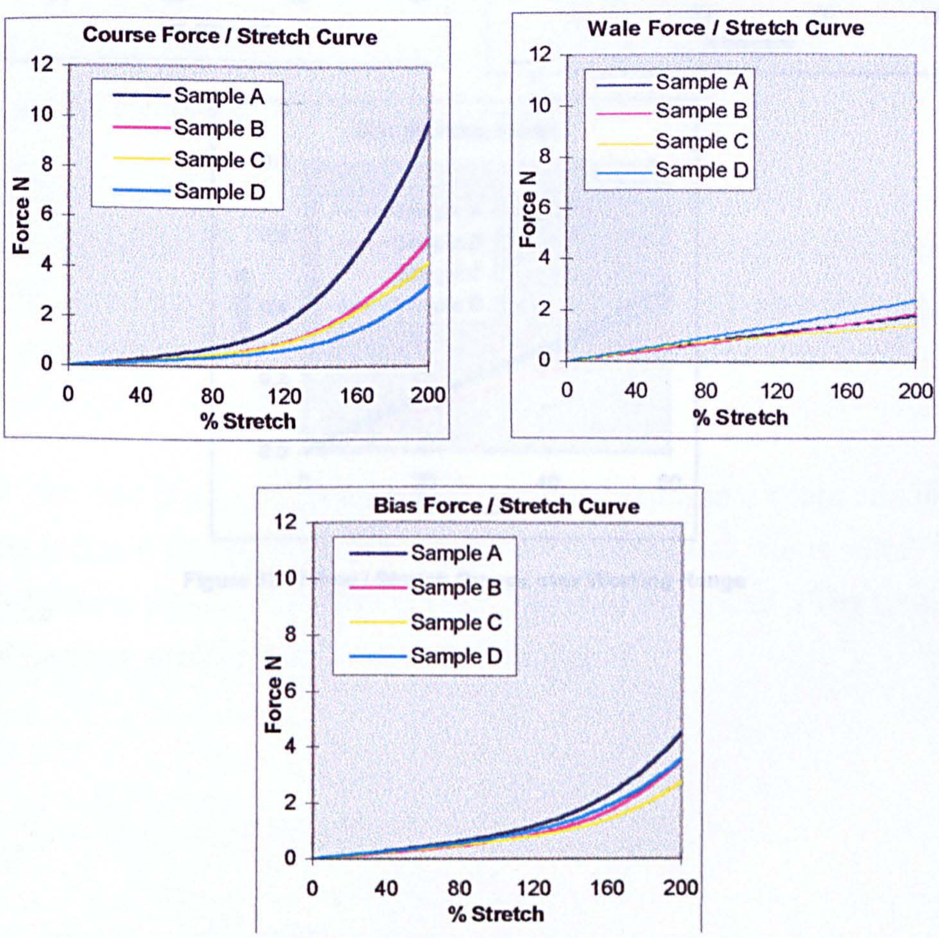


Figure 31 - Sample Orientation Correlation

2.7.1.3.3 Stretch extension working range

The graphs in Figure 32 shows the stretch extension working ranges of up to 60% stretch. It is clearly illustrated within this lower range that the course orientation offers the least resistance. The bias orientation also requires lower forces than the wale direction, which is significant when proposing a stretch reduction theory.

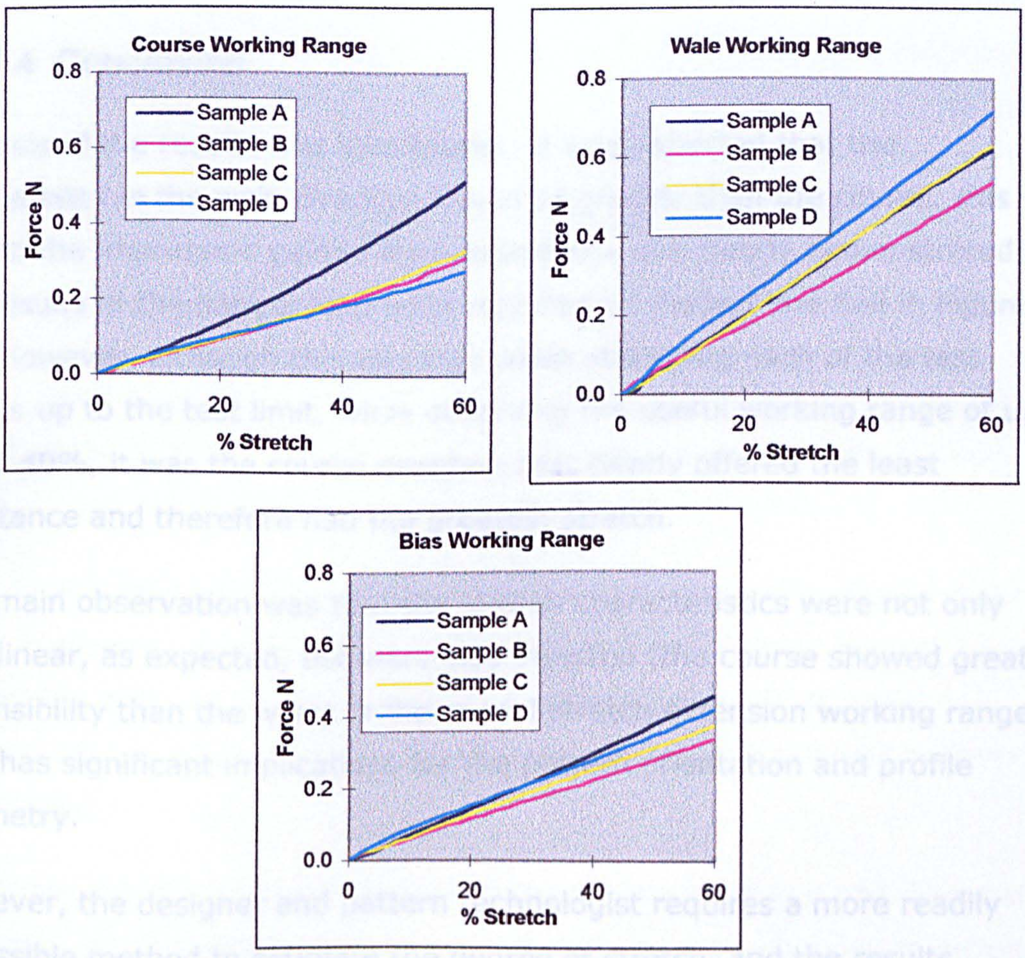


Figure 32 - Force / Stretch Curves over Working Range

2.7.1.3.4 Standard Load

The delineation used in the Aldrich 'stretch characteristics scale' in combination with the 'visual stretch scale' was used as a guide for the stretch extension working range.

Fabrics suitable for stretch performancewear approximate to the medium stretch extension working range and in the chosen test sample width of 5cm, a standard load would be 250g.

2.7.1.4 Conclusion

Analysis of the results was interesting. It was expected that the extensibility in the wale direction would be greater than the course: this was indeed the impression gained from experience and clearly demonstrated by the results of the hanger load tests reported by Ziegert and Keil in Figure 27. However, *although this was true when stretching each of the test* fabrics up to the test limit, while observing the useful working range of up to 30-40%, it was the course direction that clearly offered the least resistance and therefore had the greatest stretch.

The main observation was that the stretch characteristics were not only non-linear, as expected, but were also inverted (the course showed greater extensibility than the wale) in the crucial stretch extension working range. This has significant implications for the pattern orientation and profile geometry.

However, the designer and pattern technologist requires a more readily accessible method to estimate the degree of stretch, and the results suggested that a simple load test applying a fixed weight of 250g to a prepared sample width of 5cm could be employed.

2.8 QUAD LOAD TESTING

Literature on testing the degree of fabric stretch extension for garment pattern reduction is inconclusive on test fabric size and loading and application. Until an industry standard has been established, it is essential that the designer can follow a simple method to calculate the degree of stretch, which offers consistent results without requiring specially controlled conditions. These results should ideally show a breakdown of fabric extension into course, wale and bias, which can be used to calculate the relative stretch reduction factor. Therefore a hanger load test, referred to as the Quad Load Test Method, has been adapted by the Author, specifically to meet the requirements for measuring fabric extension for use as part of the stretch block pattern reduction procedure outlined in this thesis.

2.8.1 Aim and objectives

To calculate the degree of stretch extension at a specific load of 250g for sample fabrics in the four orientations of course, wale and bias 45° and 135°.

The development of the Quad Load Test for calculating the degree of fabric stretch extension is an intrinsic part of the procedure developed to determine a stretch reduction factor. The method, which is easily reduplicated, is specific to the requirements for stretch garment pattern production.

The original test was conducted using the course, wale and one diagonal, however, after further research this was subsequently changed to include both bias orientations.

2.8.2 Method

Rectangles of fabric detailed in Table 3 were prepared.

For each of the 5 sample fabrics a strip measuring 5cm x 20cm was cut in the course, wale and bias orientation, producing 15 test samples in total.

The test samples were identified for example as sample AC for fabric A cut in the Course direction.

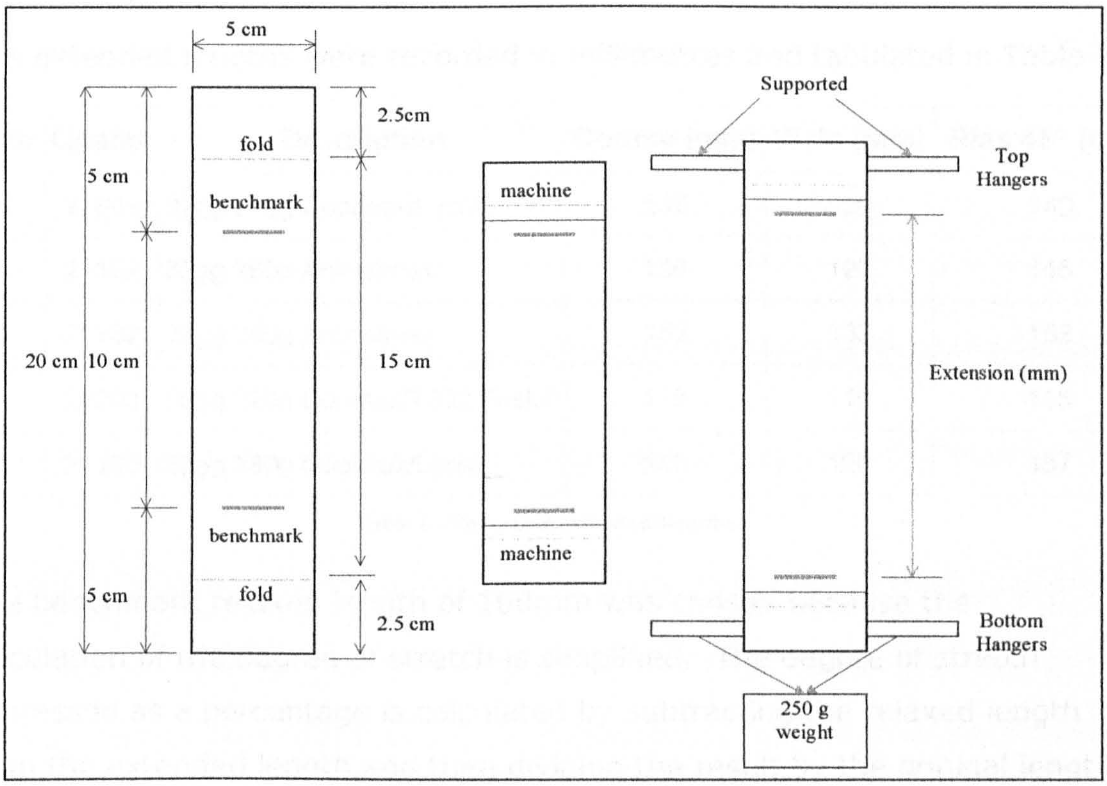


Figure 33 – Fabric Sample Preparation for Hanger Load Test

Figure 33 shows the sample fabric pattern, illustrated as a 5cm x 20cm rectangle, with benchmarks on 10cm centres between which the extended length was measured. A 2.5cm fold at both ends was machined, forming slots ready for the insertion of the hanger supports.

2.8.3 Quad Load Test Procedure

A test sample was placed on the hanger and the 250g weight applied. After allowing one minute for the fabric to stabilise, the extended measurement between the benchmarks was recorded.

The procedure was repeated for remaining samples in the course wale and 45° bias.

2.8.4 Results

The extended lengths were recorded in millimetres and tabulated in Table 5.

Code	Quality	Description	Course (mm)	Wale (mm)	Bias 45° (mm)
A	21649	32gg 210g Coolmax/Lycra	136	128	140
B	21132	32gg 260g Animalmax	156	120	145
C	21132	32gg 260g Animalmax	152	132	153
D	22203	56gg 220g Coomax/T902 Triskin	118	110	115
E	21130	32gg 180g Coolmax/Lycra	150	128	157

Table 5 - Recorded extended lengths

The benchmark relaxed length of 100mm was chosen because the calculation of the degree of stretch is simplified. The degree of stretch expressed as a percentage is calculated by subtracting the relaxed length from the extended length and then dividing the result by the original length or simply by subtracting 100 from the extended length.

$$\text{Degree of stretch} = \left(\frac{\text{extended length} - \text{relaxed length}}{\text{relaxed length}}\right)\%$$

For example the course sample fabric B in, coded BC

$$\text{Degree of stretch } s = \left(\frac{156 - 100}{100}\right)\%$$

$$= 56\%$$

2.8.4.1 Quad Angle Stretch Distribution

Entering the test results into a spreadsheet enabled a graphic representation of the distribution of stretchability throughout 360° of fabric orientation to be displayed. This method was adapted from Lindberg (1966:60) which was used to compare the bias stretch in woven double or bi-directional stretch and a non-stretch fabric.

Although only three measurements were taken for each fabric, corresponding to 0°, 45° and 90° rotation, it was assumed that inverse symmetry would apply. However fitting experimental garments led to questioning the use of a single bias extension measurement only and it was subsequently found that not all stretch knit fabrics had a corresponding degree of stretch between the bias at 45° and at 135° as recorded in Table 6. The results would appear to indicate that to achieve a consistent contour fit between garment right and left sides requires an equal bias measurement although small differences can be absorbed within the stretch fabric parameters this may not always be appropriate. In compressive garment technology particularly in medical applications an equal bias measurement may be crucial to obtaining an equal pressure on the body between right and left sides.

Code	Quality	Description	Course	Wale	45° Bias	135° Bias
A	21649	32gg 210g Coolmax/Lycra	136	128	140	135
B	21132	32gg 260g Animalmax	156	120	145	145
C	21132	32gg 260g Animalmax	152	132	153	148
D	22203	56gg 220g Coomax/T902 Triskin	118	110	115	114
E	21130	32gg 180g Coolmax/Lycra	150	128	157	147

Table 6 – Quad Load test results

2.8.4.2 Quad Angle Plots

The angular stretch distribution curves for both the single and double bias measurement tests are compared in Figure 34.

If a fabric were to behave as a simple lattice structure that had very limited stretch in the course and wale directions, the resulting stretch distribution curve would be represented by four vectors radiating from a central point. A stretch distribution plot of a fabric that extends uniformly in all directions for a given load would be circular.

The angular stretch distribution plots all clearly demonstrate that the highest stretch is in the course direction. Samples B, C and D show vertical symmetry. Samples A and E demonstrate a lack of symmetry in the bias stretch.

These plots made a significant contribution to the understanding of stretch fabric

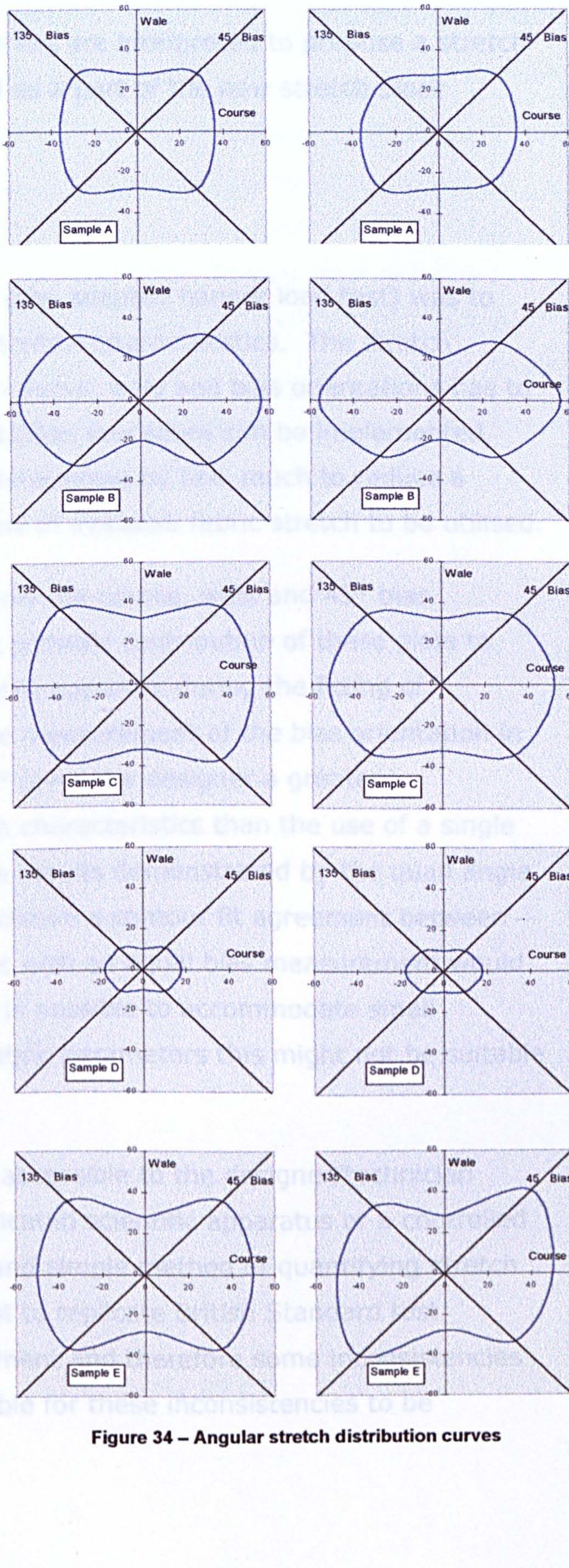


Figure 34 – Angular stretch distribution curves

characteristics, the impact of bias stretch on pattern profile geometry and the optimal pattern orientation for dynamic fit.

The angular stretch distribution curves are interpreted to propose a stretch reduction theory, which is detailed as a part of the new stretch block pattern drafting procedure.

2.8.5 Conclusion

The purpose of the quad load test (the adapted hanger load test) was to assist the designer in quantifying stretch characteristics. The stretch extension of sample fabrics in the course, wale and bias orientations has to be calculated before a pattern reduction procedure can be implemented. The pattern reduction procedure determines by how much to reduce a pattern to accommodate the degree of available fabric stretch to be utilised.

In the original hanger load tests only the course, wale and 45° bias extension were measured and the possible contribution of these plots to garment comfort and fit only became apparent during the fitting of experimental garments. Therefore measurement of the bias orientation in the two directions of 45° and 135° gives the designer a greater understanding of the fabric stretch characteristics than the use of a single bias extension measurement. The results demonstrated by the quad angle distribution plot indicate that to achieve a contour fit agreement between garment right and left sides, fabric with an equal bias measurement would be more appropriate. Although it is possible to accommodate small inconstancies within the stretch fabric parameters this might not be suitable for all applications.

The new quad load test is readily accessible to the designer/technician because it does not rely on complicated scientific apparatus or a controlled environment. It is a convenient and simple method of quantifying stretch extension, which does not attempt to replicate British Standard test conditions in a controlled environment and therefore some inconsistencies will occur. Despite this it is possible for these inconsistencies to be accommodated within the fabric stretch reduction parameters and, therefore, should not detract from the intended purpose of the simplified test procedure. The sample preparation and testing are easily reduplicated, which is vital.

Until an industry standard has been established, it is essential that the designer can follow a simple procedure, which offers consistent results without requiring specially controlled conditions. The new quad load test results show a breakdown of fabric extension into course, wale and bias, which were used to calculate the relative stretch reduction factor. This is detailed later.

2.9 SUMMARY OF KNIT STRETCH FABRICS

The development of stretch knit fabric technology is increasingly sophisticated. However, it is the interlinking yarn loops and imparted stretch characteristics that are of interest in this study as this makes stretch knit fabrics eminently suited to contouring the body.

When uniaxially applying tension to a rectangle of fabric, the stretch characteristic observed at the centre of the fabric will be linear. Visualising the stretch characteristics of a rectangle with the sides unsupported shows that when lateral forces have been applied, the tension will cause the fabric to waist at the edges. Waisting, although visually minimal in the conducted tests, clearly indicates the effect of bias stretch characteristics in action. Whilst the bias stretch for specific areas cannot be isolated and quantified, the bias stretch characteristic is significant in maximising the fit potential through the pattern profile geometry in areas where directional changes and protrusion affect the fabric displacement around the body contour. The visual understanding of the overall knit stretch fabric distortion characteristics is essential to the process of pattern production through garment fit evaluation.

If a garment pattern is perceived as being constructed from an array of geometrical shapes, areas that are vulnerable to the greatest deformity can be defined according to the predominant geometric shape. Increased tension applied to triangles brings about a non-linear stretch characteristic. Although the centre gridline of fabric may not appear to differ visually across a range of angles, the applied force for a given fabric extension must reduce with the angle of the triangle. The triangle deforms in relation to the lateral forces of the fabric construction, which decrease towards the apex of the triangle. The shape of the fabric affects the stretch characteristics. The transposition of the sample shape deformation and their significance for pattern geometry is explained in Chapter 5.

It is apparent from the review of existing methods, both manual and mechanical, that there is no consensus of opinion on objectively quantifying stretch extension. Therefore an understanding of fabric stretch extension characteristics was sought using two methods, a hanger load test and Instron force extension testing.

Hanger load testing was conducted prior to the Instron testing and was undertaken to gain an understanding of stretch fabric extension characteristics when using different widths but retaining the same measurement unit length and load to determine the fabric sample width to be used in successive tests.

The results suggested that a 5cm fabric sample width and a 10cm benchmark length was suitable for use in further testing. The tests confirmed that the larger the fabric area the greater the force that is needed to deform the fabric and this is significant when analysing the fit quality relationship to the pattern geometry.

The relationship between the applied force and fabric extension was undertaken using Instron tensile testing apparatus. Analysis of the results was interesting. It was expected that the extensibility in the wale direction would be greater than the course, which it clearly was at the highest extension levels. Paradoxically the course showed greater extensibility than the wale when observed at the useful stretch extension working range of up to 30-40%. The course direction clearly offered the least resistance and therefore had the greatest stretch. The implications for the pattern orientation and profile geometry are significant.

The Instron testing results suggested that a simple load test applying a fixed weight of 250g to a prepared sample width of 5cm with a benchmark length of 10cm could be employed to quantify stretch extension within the useful working range. However, a more readily accessible method to determine the degree of stretch needed to be employed.

It is the combination of the degree of fabric stretch, the proximity of the garment to the body and the modulus that determine pattern reduction. The purpose of the new quad load test is to calculate the stretch extension of sample fabrics in the course, wale and 45° and 135° bias orientations, referred to as the quad angle plot, which will be introduced into the stretch block pattern reduction procedure.

The measurement of the bias orientation in the two directions of 90° and 135° gives the designer an understanding of the distribution of fabric stretch characteristics. The quad angle plot demonstrates the stretch distribution. The results appear to indicate that if a consistent contour fit between the right and left sides of a garment is to be achieved then fabric with an equal bias measurement should be used although small differences can be accommodated within the fabric stretch tolerances.

The quad load test is readily accessible to the designer/technician. The sample preparation and testing are easily reduplicated and the method is not reliant on complicated scientific apparatus or a controlled environment. Although, as a consequence some inconsistencies can occur, this should not detract from the intended purpose of the test procedure.

Visualising the geometrical fabric stretch deformation and the quantification of the amount of available stretch extension in the course, wale and the 45° and 135° bias directions in the low modulus region promotes understanding stretch fabric behaviour. This knowledge contributes to predicting the proximity of the garment-to-body fit relationship and the application of the reduction factor in the vertical and horizontal directions of the pattern profile to produce a consistent garment fit quality outlined in Chapter 5.

CHAPTER THREE

PATTERN GENERATION

3.1 EVOLUTION OF THE GARMENT PATTERN

Over the past two decades industry has attempted to standardise pattern sizing. With the introduction of the fashion for a loose fitting, *shoulder pads in everything* style of garment, this was partially achieved, but this diversion was at the cost of a true understanding of the body shape and movement, found in traditional, bespoke tailoring pattern design techniques.

The earliest woven fabric garments were little more than a length of material draped to form a covering; examples of this are the Indian sari and the plaid of the Scottish highlander. This uncomplicated raiment was easy to reproduce without the aid of a pattern. The introduction of seams to remove excess material in a garment meant that the garment profile could be brought nearer to the contours of the body. The first garments that made any attempt to follow the contours of the body were sleeveless; they had just a slit or a hole for a person's head and arms. The bifurcation of the lower portion of a garment came about to allow greater freedom of movement whilst at the same time protecting the legs. The progressive variations of the silhouette can be visualised as the placement of seams was introduced as a means of changing the shape and fit of a garment.

The production of garment patterns originated to help the professional tailor and dressmaker with the garment-making process. Early patterns were only a guide and it required an extremely accomplished person to create a garment that actually fitted; the techniques of pattern cutting and sizing were still in their infancy. Pattern making systems evolved through the necessity for a consistent approach to garment manufacture, particularly for those garments mass-produced and ready-made for the main body of the military at a time when only the officers had made-to-measure garments. Even in the earliest times, in seaports like Bristol, garments were produced to standard sizes during slack times in preparation for those who had not the time in port to wait for a bespoke outfit (Hulme 1945:37). Traditionally men's garments were custom made by tailors who were organised in craft guilds. Women employed a dressmaker to make their gowns, with the exception of their riding habit, which was usually made by the tailor.

During the late 1800's the 'tailor-made' (a suit) became fashionable attire for women. This fashion and the growth of the 'ready-to-wear' clothing industry heightened the need for pattern drafting systems, size charts and technical information to reproduce standardised garments. The bespoke tailoring trade was in a unique position to draw on a wealth of knowledge devoted to cutting and fitting the human body. There was no shortage of people to disseminate this knowledge through trade journals, textbooks, trade schools and the new technical colleges. Innumerable sizing and pattern cutting systems were espoused, however, these were often grossly inaccurate empirical methods based on personal opinion and preference.

Although these systems were inaccurate, the observations on the divergences of the human form were enlightening. The way in which patterns were manipulated and altered to fit is still valid today. In tailoring convention it is the desired silhouette, which is so vital, the architecture of the shoulders, the hang of the garment, the trousers constructed to stand (without needing body) in a perfectly aligned crease. Perception of the body within the external framework of clothes is the key. The garment construction around the body is padded and manipulated as the tailor strives to conceal the anomalies of the individual. Therefore, the cutter always seemed to have had a mental picture of the three dimensional body whilst concurrently working in the two dimensional plane. In his book, 'The Practise of Garment Pattern Making', W. H. Hulme (1946) discusses the first principles of a pattern maker standing at the drafting board with a flat piece of paper lying before him.

> Out of this he is to make his pattern. He has beside him a number of measurements, and in his mind there is an exact idea of the figure he is drafting for; how it stands and moves, its posture and action. On to that sheet of pattern paper he will place certain lines and many points; these points and lines will give the size and shape of the form. Other lesser considerations will, of course, arise during the process, but size and shape are paramount. He may be making a basic pattern, embodying only the

> measurements, placing the anatomical points, and not concerning himself with style features of any kind. This is the type of pattern, which faithfully reproduces the parts of the body to be clothed, and which can be used as a base, or starting point, for a later garment pattern. It is a true and tested base on which any sartorial superstructure may be reared: into which any style features may be introduced. (Hulme 1946:23)

The ability to keep in the 'minds eye' the three dimensional body form, the stretch fabric potential and the two dimensional pattern profile, is an essential step on the road to innovation. The garment industry over the past two decades has attempted to standardise pattern sizing. The fashion for 'one size fits all' type of garment, was at the expense of an awareness of the relationship between the shape, posture, body movement and the garment pattern, which is fundamental in traditional bespoke tailoring. Most block patterns used by clothing manufacturers have been developed and adapted by numerous people over many years. This means that the rationale for implementing the pattern profile, the apportionment of body measurements and those applied measurements for tolerance or ease is often lost (Gray 1999:3).

3.2 PATTERN CONSTRUCTION METHODS

A pattern is a diagram that has been constructed in a prescribed manner from a set of measurements. This serves as a template from which a final product can be made. There are three methods for generating patterns: drafting a basic block pattern; designing a flat pattern; draping or modelling on the stand (a static representation of the human form). Indeed there are four, if you count the widely used method of taking a pattern from a competitor's garment!

3.2.1 Drafting

Drafting is the drawing of a block pattern on paper according to a specific procedure, the co-ordinates of which are based on a set of measurements derived either from a size chart or an individual or dress stand. The resulting pattern has a relatively simple shape with no design embellishments and is used as a basis for style development.

3.2.2 Flat Pattern

Flat pattern design involves the modification of the basic block pattern, which is manipulated and adapted to produce a new pattern profile for the garment design style specification.

3.2.3 Modelling

Modelling on the stand is the moulding or draping of cloth on either a stand or a person. The profile of the cloth pattern or toile is then transferred onto paper. The pattern can be modelled as a basic block pattern or directly to the final design creation. Most designers use a combination of all three methods. However, modelling can be unsatisfactory for the shaping of stretch garments because it is difficult to maintain a constant hand tension when pulling the stretch fabric around either the form or a person.

Traditional draping and fitting techniques are also problematic; it is awkward to cut away or insert fabric and make adjustments using pins.

3.3 PATTERN ORIENTATION

Pattern orientation is the positioning of a pattern piece on fabric in a particular grain direction. This can have a profound effect on the hang and fit of the finished garment.

Conventionally patterns have been orientated with the vertical, warp thread or wale loops corresponding to the vertical plain of the garment and the horizontal weft threads or coarse loops lying across the garment. Fabrics were not usually cut on the diagonal at 45° (bias). During the 1920's a number of designers began to experiment with draping fabric on the bias but one designer in particular is synonymous with this cutting technique.

3.3.1 Bias Cutting

The French couturier Madeleine Vionnet is famous for her innovative 'bias cut', which she perfected in the 1920's. This revolutionary contribution to apparel design was achieved by cutting all or part of a garment on the diagonal or bias. Fabric cut in this way stretches and moulds over the body contours. She did not approve of the restrictive underwear, which was *de rigour* at that time and preferred to work with the natural contours of the body; she "*moulded the dress to the woman rather than the woman to the dress.*" (Milbank 1985:160). Vionnet must have observed the inherent differences in the traditional approach where garments were cut with the pattern pieces aligned on the warp grain of the fabric. Her non-traditional approach to seam placement and seam sewing techniques also enhanced her innovative style. The stretch characteristics of some knit fabrics can be equated with the moulding qualities only found in bias draping.

3.3.2 Woven fabric structure

The basic structure of a non-stretch woven fabric at its simplest is the interlacing of two sets of threads lengthwise (warp) and crosswise (weft)

(Figure 35), which produce a criss-cross structure. The latticed structure of the thread forms the grain lines in the fabric.

The warp yarns run lengthwise parallel to the selvage. Generally the warp yarns are subject to greater stress than the weft yarns during weaving and

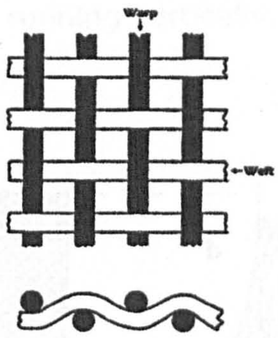


Figure 35 - Plain Weave. Source: Scrimshaw and Bingham (1994:2)

consequently it is possible to use weaker threads in the weft direction (Scrimshaw and Bingham 1994:1). This is one reason why the grain characteristics can be asymmetric.

Patterns can be cut in any one of three directions: the lengthwise grain, the crosswise grain and on the diagonal or bias (45°) grain, see Figure 36.

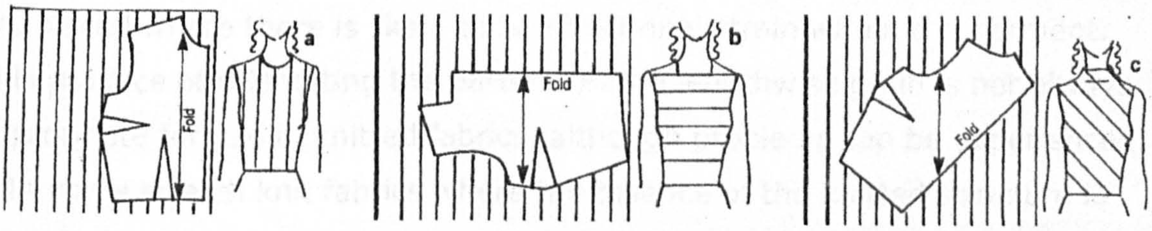


Figure 36 – a) Lengthwise Warp b) Crosswise Weft c) Bias Orientation. Source: Stanley (1991:82)

It is good practice to cut fabric with the lengthwise grain running centrally down the pattern pieces; cutting a pattern skewed off the true grain line can adversely affect the hang of the finished garment. Fabrics with asymmetric grain characteristics, cut on the true bias, can also have an adverse effect on the symmetry of a garment. This can sometimes be partially overcome by placing seams at the centre front and back. The warp and weft threads are generally inelastic, unlike the bias direction, which is flexible and combines the properties of stretch and cling. When bias cut fabric is extended in a given area it will contract directly above and below. Consequently the fabric will become narrower and shorter, see Figure 37.

Patterns do not have to follow the convention of aligning the pattern piece with the fabric warp grain running vertically. It is usually assumed that the

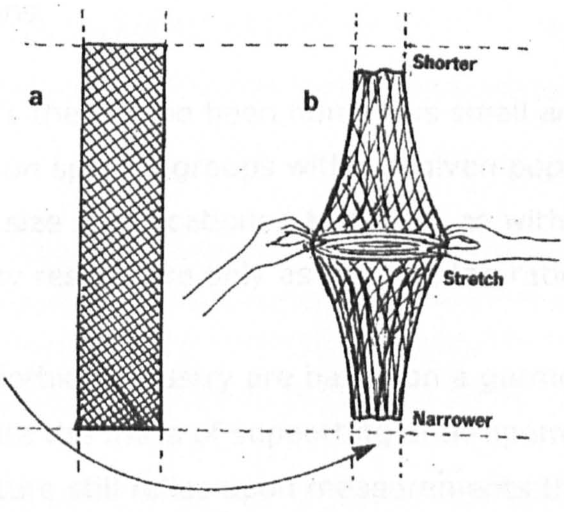


Figure 37 - Bias Characteristics. Source: Stanley (1991:83)

strong yarns will be in the warp and the softer decorative yarns in the filling or weft. Therefore, it is sensible practice to ensure that the strongest yarns are placed where there is likely to be directional strain within the garment. This practice of orientating the pattern on the lengthwise grain is not always appropriate for use in knitted fabrics, although problems can be experienced with some stretch knit fabrics where the balance of the knitted structure is asymmetric. The surface pattern design may also inhibit pattern orientation. There is also no hard and fast rule as to which side of the fabric should be used as the outer. This is entirely dependent on the function and aesthetics of the design.

3.4 ANTHROPOMETRY

Anthropometry is the study of human body measurements for use in anthropological classification and comparison. The data is not only used for sizing, it also has applications in ergonomics and product design. Variations in human physiques or body types are infinite; an obvious example is the distinction in shape and proportion between men and women. Further proportional differences exist between people of different racial origins and geographical locations.

Since the late 1800's there have been numerous small anthropometric surveys carried out on specific groups within a given population to determine garment size specifications. However, as with every scientific approach, the survey results are only as good as the rationale behind it.

All patterns in the clothing industry are based on a garment size specification. Despite the mass of supporting anthropometric data, traditional manufacture still relies upon measurements that have emerged through trial and error.

3.4.1 Apparel Sizing Surveys

There have been five large-scale surveys carried out between 1948 and 1982 designed specifically for the clothing industry (Winks 1997).

The same basic procedure was used in all the surveys. The measurements were taken using standard tape measures and various calibrated instruments. The body posture remained constant, with the exception of the body rise measurement, which necessitated the subject to be seated. The subject stood erect with feet slightly apart and arms relaxed at the sides with the palms turned inwards towards the body. The subjects wore a specially designed measuring costume and the specified anatomical landmarks were marked on the body with a stain pencil.

Each survey used the same four groupings of measurements (Cooklin 1990:9).

1. Horizontal girth measurements, which were taken around the body, e.g. bust girth, waist girth, armscye girth.

2. Arc measurements for specified parts of girth measurements. An example is the bust arc anterior as part of the bust girth.

3. Vertical measurements, the majority of which relate to the heights of various girth lines from the base of the foot such as cervical height and waist girth height.

4. Anthropometric measurements of width and length which contain primary and secondary measurements of width and length for example armscye, width across back and nape to waist.

There were, however, slight differences between the surveys.

3.4.1.1 France

In 1968 the French survey was undertaken by the Centre for Clothing (CEITH) on behalf of the Federation of Clothing Manufacturers. The sample consisted of 8,000 women and 26 measurements were taken from each subject.

3.4.1.2 West Germany

In 1970 the Textile and Clothing Research Institute Hohenstein, at the request of the German Association of Clothing manufacturers, carried out a large-scale survey which was repeated in 1981. The survey compiled twenty-one separate measurements taken from a cross sectional representation of ten thousand women. Reports were published in 1973 and in 1983.

The first report contained proposals for a new sizing system, which was adopted in West Germany. The findings of the second survey report were similar to the first with no significant changes in measurements and proportions. Subsequently both sets of results were used to develop the German sizing system (Brunn 1983:102-103).

These two surveys from France and West Germany form the basis of the European sizing system currently in use.

3.4.1.3 America

An American survey took place between 1948 and 1959 and covered a sample of ten thousand women, each subject had forty-nine body measurements taken (O'Brien and Shelton 1941).

3.4.1.4 England

The English survey, which was similar to the American, was carried out during 1951 and consisted of thirty-seven measurements taken from fifty thousand women between the ages of eighteen and sixty-five (Kemsley 1957). Most of the subjects wore a specially designed costume during measuring and some wore their own undergarments; calculations were made to approximate the measurements with those taken over bare flesh. In instances where constricting underwear was worn it was impossible to formulate an accurate allowance. (It must be remembered that in 1951 it was inconceivable that a woman would not wear a girdle and conform to the prevailing 'natural' silhouette!)

The report, which was published in 1957, contained a detailed analysis of the measurement and size groupings of a large cross-section of the female population within the eighteen and sixty-five age range. These reports were inadequate as no account was taken of body shape contour distribution and posture. As we mature the body starts shrinking and reducing in height. This process usually starts during the late thirties and becomes more significant beyond the age of fifty (Goldsberry and Reich 1989:42-44).

3.4.1.5 The Dress Stand

Stand designs are based on the available survey data, which offers no information on body shape proportions and posture. Even with the wide variety of shapes and postures available, it is almost impossible to find any individual to match the stand dimensions. This imposes difficulties in transferring a body contour garment to an individual to assess the garment fit quality for mobility and comfort levels.

The inclusion of tolerances is an impediment for body contoured garments as the shape in certain areas is thickened, for example around the neck, chest and shoulders. The shape of the stand in the area of joints is also problematic, particularly where the arm is attached to the body.

However, the fundamental problem with stand design for contoured garments is that the form is neither malleable nor mobile, which is particularly frustrating when the final garment is designed for movement.

The positive attribute of the dress stand is that it limits the variables in testing procedures by being consistent, it is available at all times and never looses weight!

3.4.1.6 Anthropometric Data

The process of physically gathering anthropometric data for pattern generation and stand design is not a straightforward procedure and can be difficult as well as time consuming. Body scanning techniques are far less intrusive and often more time and cost effective than using manual-measuring techniques and although this technology will be of enormous benefit to the garment industry, it does require refining to consistently replicate a complete body contour profile. Conventional pattern cutting and grading techniques, which are modified to the nearest size, without a system for identifying the garment to body relationship will, therefore, even with rapid acquisition of this accurate measurement data, only enable manufacturers to reproduce the same old inconsistent garment fit quality but in a shorter lead time.

because garment pattern co-ordinates, at present, follow conventional pattern cutting and grading techniques, which are modified to the nearest requisite size, without a system for identifying the garment-to-body fit quality relationship.

3.5 BODY SHAPE

Today in Britain, women's measurements and sizes are based on surveys carried out nearly half a century ago. Unfortunately, the measurements gave no indication of the shape, proportions or posture of those measured. Over the years manufacturers have tried to standardise on garment sizing which is extremely difficult without first defining the garment-to-body fit relationship. If we look around we will observe many different shaped women who may have similar measurements but are vastly different in body shape, proportions and postures. All drafting systems to a greater or lesser extent make assumptions about the body shape based on derived measurements. It is the shape proportion and posture of a person that is important, but replicating the three-dimensional body shape in a two-dimensional pattern profile can be problematic.

Body shape can be described by taking the different proportions between the form, width and length of body segments. The shape of the body in Figure 38 is defined by these proportions. It is clear that the woman in the first figure is short, then there is a medium height and a tall woman. They all have the same bust, waist and hip measurements, however, the proportion of the torso is different.

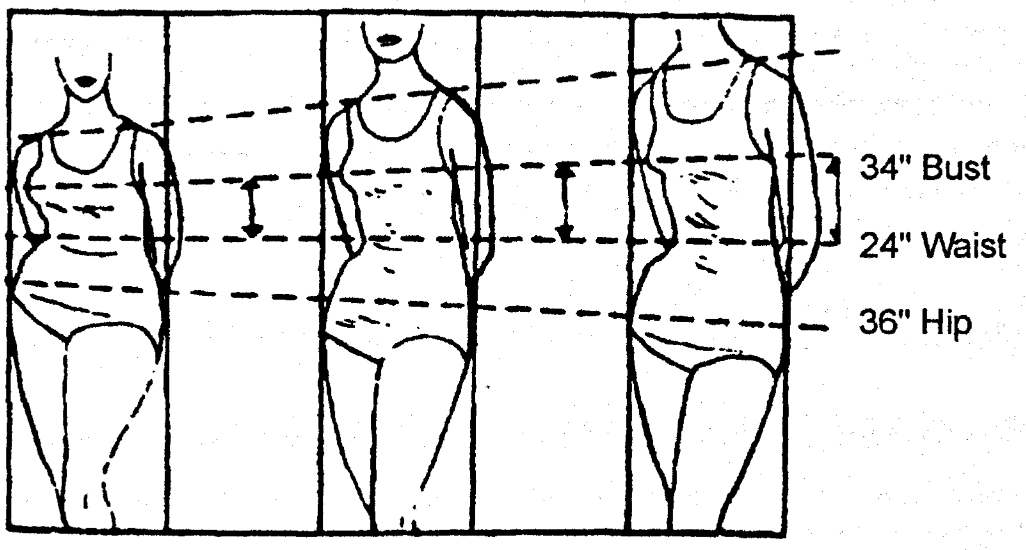


Figure 38 – Variations in Body Shape and Proportions. Source: Horn (1991:369)

The torso can also differ in width from front to back and side to side. For example, by viewing the front and side of the two bodies illustrated in Figure 39, it can be can seen that the woman on the left is wide from side to side but narrow through from front to back. The converse applies to the woman on the right. So although they would take the same size, they are different in shape and proportions.

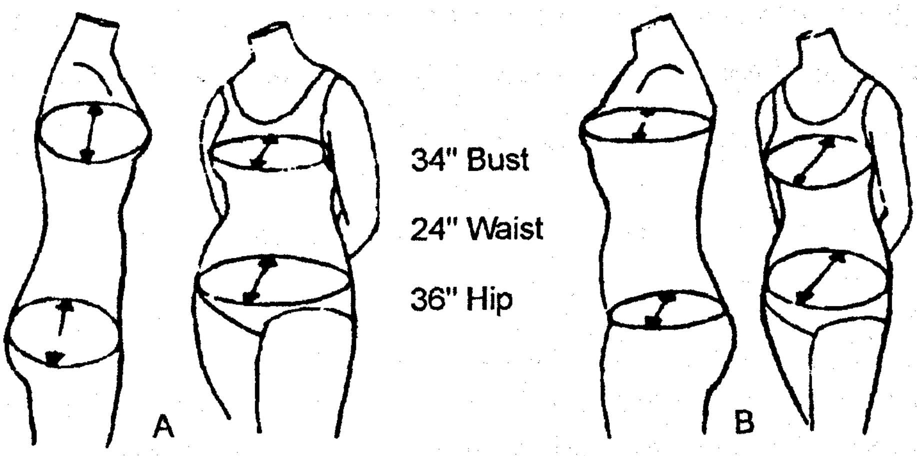


Figure 39 – Variations in Body Shape and Proportions. Source: Horn (1991:369)

Therefore, to obtain a desirable fit quality for freedom and comfort, pattern design systems need to revise conventional pattern drafting techniques which use derived co-ordinates and interpret measurement data dynamically manipulating direct body measurements. Then with the introduction of a garment-to-body fit classification system this would enable manufacturers to produce garments for the shape, posture and fit preferences of either an individual or a target market segment.

3.6 SOMATOTYPING

Anthropometric somatotyping is a classification system that describes both male and female body shape and composition. Somatotyping emerged as a consequence of Sheldon and fellow collaborators Stevens and Tucker developing a systematic approach to studying personality based on physical appearance (Sheldon et al 1940). In 1940 they published 'The Varieties of Human Physique: An introduction to Constitutional Psychology', which outlined a scientific method for grading human physiques that *transcended the boundaries and anomalies of language*. Three extremes of human physique were identified as components that appear in varying degrees in each individual and provided a schema for differentiation between individuals. The first component was defined as Endomorphy, the second Mesomorphy and the third Ectomorphy. Figure 40 illustrates Seldon's somatotype definitions.

3.6.1 Sheldon's Somatotype Definition

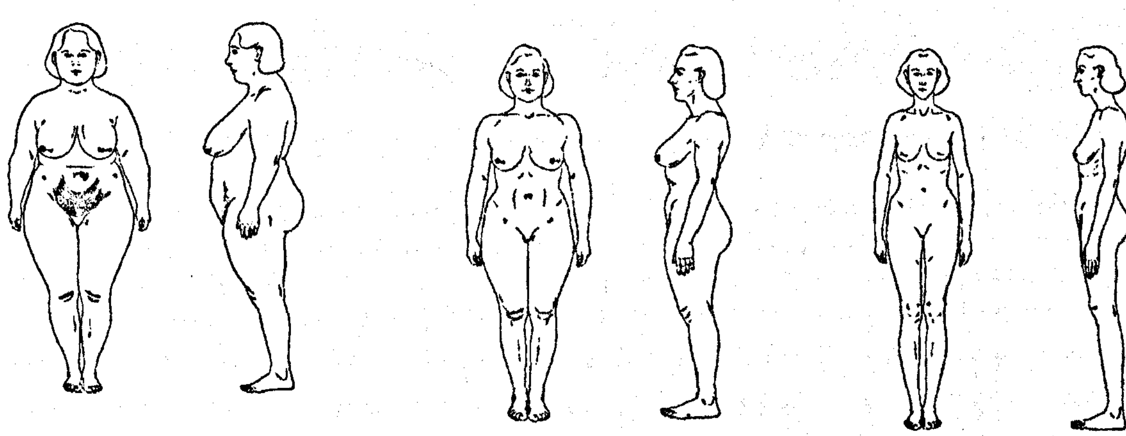


Figure 40 – Endomorphy, Mesomorphy and Ectomorphy Source: Sheldon et al (1940:298, 294, 291)

Endomorphy is defined as the relative predominance of soft roundness throughout the various regions of the body. When endomorphy is dominant the digestive viscera are massive and tend relatively to dominate the bodily economy.

Mesomorphy is defined as relative predominance of muscle, bone and connective tissue. The mesomorphic physique is normally heavy, hard and rectangular in outline. Bone and muscle are prominent and the skin is made thick by a heavy underlying connective tissue.

Ectomorphy is defined as relative predominance of linearity and fragility. In proportion to the body mass, the ectomorph has the greatest surface area and hence relatively the greatest sensory exposure to the outside world (1940:5).

3.6.2 Sheldon's Classification Procedure

The classification procedure of somatotyping began with front, back and side views of the human body recorded on the same film. The negative from the photograph was then measured and the body divided. Overall seventeen horizontal diameters were measured, see Figure 41.

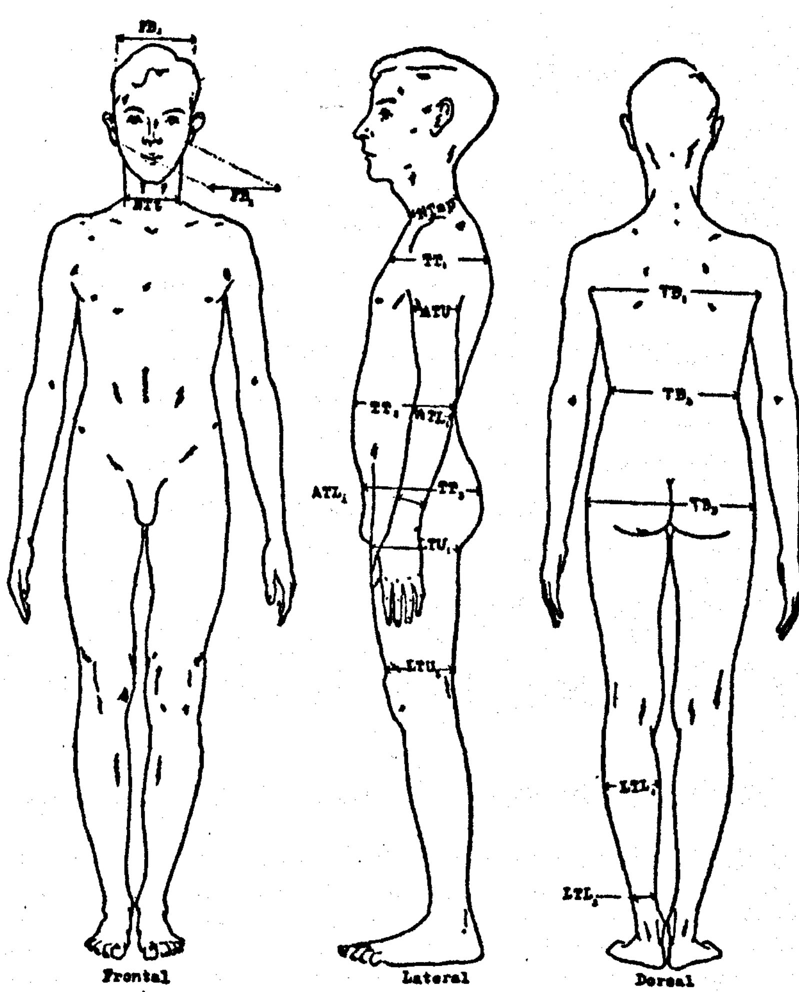


Figure 41 – Sheldon Body Diameter Measurements. Source: Sheldon (1940:55)

These measurements were subsequently divided by the height of the subject in order to convert it into a ratio, as every measurement was then expressed as a ratio to stature. The somatotype was designated by three numerals, one for each component. The prints of the photographs were then examined and the approximate strength of each component of the body as a whole was estimated. These five regions were then ranked on a scale of one to seven with one exhibiting the minimum degree of a component part and seven displaying the maximum.

This procedure makes it possible to assign the subject's position using digits relative to the scale for each component. A physique ranked at 711 is extreme in endomorphy and a minimum in the other five components. A ranking of 171 would be extreme mesomorphic, extreme ectomorphy would be ranked at 117 (1940:6-7).

3.7 SOMATOCHART

The research of William Sheldon and his collaborators, to classify the human physique in relation to psychological factors, was refined by Heath and Carter (1967:67) as "a measure of shape not of size". They developed a somatochart to plot the position of an individual's body shape category. The Heath-Carter system is a shorthand way of describing both male and female body types based on body measurements. The subject is defined by three numbers, each representing one component (1967:61-70). Ten measurements are taken to calculate the three components in the following order:

1. Endomorphy measures skinfold to calculate relative fatness of the person in relation to height.
2. Mesomorphy represents musculoskeletal development and estimates fat components and bone diameters. The taller the person the larger the musculoskeletal dimensions must be to maintain the same mesomporphic level.
3. Ectomorphy defines height and mass cubic relationship, the relative linearity of the individual physique. A high rating indicates lightness for a given height.

Each person is rated on each of the three components, which identifies the individual's body shape category. This is then positioned on a somatochart, which illustrates the various categories of sports participants (see Figure 42).

This method is widely used to classify military personnel and sports people. In terms of sports participants a typical endomorph would be a sumo wrestler. A typical mesomorph is a power athlete, such as a javelin or discus thrower. Typical ectomorphs would be ballet dancers, gymnasts and marathon runners.

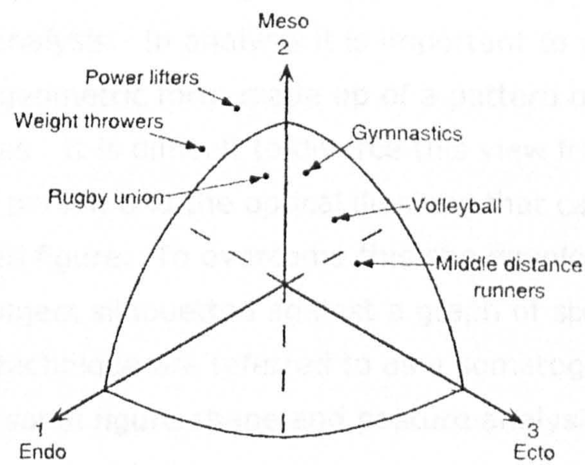


Figure 42 - Somatochart Illustrating the Somatotypes of Selected Elite Male South Australian Sports People. Source: Withers et al (1986:58)

3.8 SOMATOGRAPH AND POSTUREGRAPH

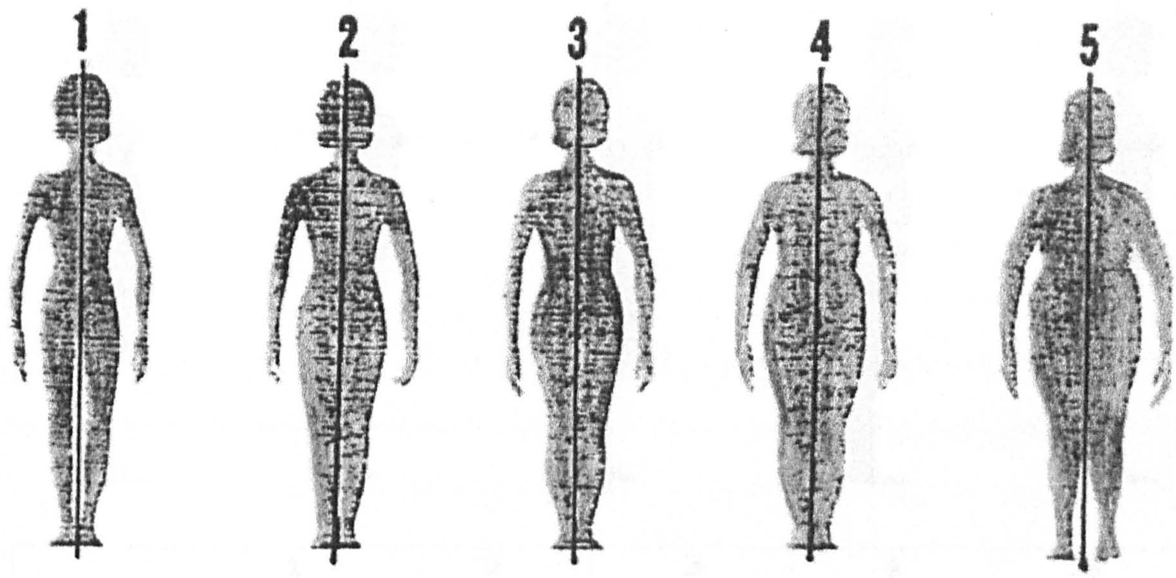
A somatograph is a photographic technique developed by Helen Douty (1954,1968) as an aid to figure analysis and design selection. Her method drew on the body shape classification researched by Sheldon (1940) and his collaborators. She found that commonly used methods of figure analysis all had their own inadequacies and objectivity posed a major problem in self analysis and peer analysis. In analysis it is important to view the body as a three-dimensional geometric form made up of a pattern of planes, solids, curves and flat areas. It is difficult to divorce this view from the normal aesthetic view of a person and the optical illusions that can be brought about by the clothed figure. To overcome this she developed the method of photographing a subject silhouetted against a graph of six-inch squares. The results of this technique are referred to as a somatograph, which is an accurate and impersonal figure shape and posture analysis.

The subject wears only a bra and briefs or a smooth two-piece bathing suit and is required to stand naturally and not in a posed position. The posterior (back view) of the subject is centred on a vertical line of the graph and then photographed. The subject is then repositioned in the lateral (side view); the ankles are centred on the vertical line of the graph. Three photographs are taken: a view of the posterior, the lateral view and a second photograph of the posterior with the hair fastened up in a net so that the neck and head carriage will show (1954:26).

The proportions, curves, irregularities, weight distribution and other characteristics show quite clearly. The method has been termed visual somatometry because details of body characteristics can quickly and easily be seen when presented in graph form. This, in essence, is a modification of silhouette photography. Two main problems that require critical decisions are concerned with maintaining the position of the subject, and the distance from the camera to the subject to avoid creating a parallax. The somatograph was then used to develop a system for the classification of figures.

Somatographs were taken of three hundred women students at Auburn University in the USA to determine the body scale rating standard which included a posture scale (1968:27-29). Figure typing was derived from Douty's body build classification scale of 1-5. The scale was based on the assumption that it is the relationship of all the body segments to each other in terms of size and weight and is not dependant upon height to determine the scale rating which was similar to Sheldon's somatotypes. A figure of any height could be located in any one of the categories, which ranged from 'Thin, Slender, Average, Stocky through to Heavy', see Figure 43.

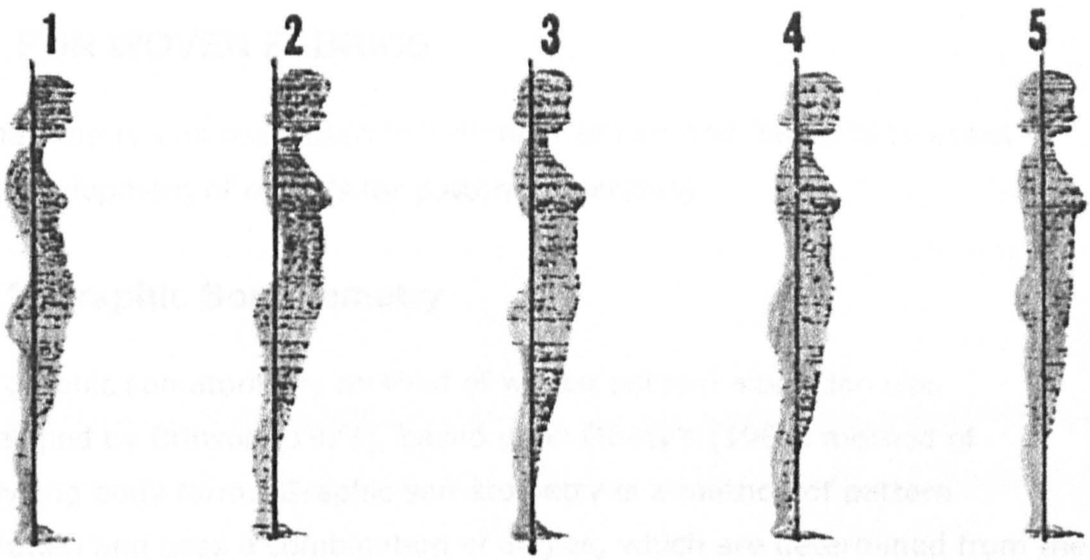
Douty's posture scale was developed in the same manner from a posturegraph, which is the view of the subject photographed from the side. The constituent segmental elements were then identified and listed under the categories 'Bad, Poor, Average, Good and Excellent', see Figure 44. The alignment of body segments can be compared with the balance line and malalignment can be readily identified. The posture scale then aided self-evaluation.



	1 **Thin**	2 **Slender**	3 **Average**	4 **Stocky**	5 **Heavy**
Chest	Flat	But small	Average	Large	Markedly prominent
Midriff	Very flat	Flat	Average	Curves	Markedly prominent
Waist	Too thin	Slender	Average	Thick	Not defined
Abdomen	Very flat	Flat	Slightly rounded	Protruding	Very prominent
Hips	Very lean	Slender	Average	Heavy	Too heavy
Thighs	Skinny	Slender	Average	Heavy	Very heavy
Arms	Bony	Slender	Average	Thick	Markedly heavy
legs	Bony	Slender	Average	Thick	Markedly heavy
Shoulders	Very narrow	Narrow	Average	Broad	Markedly broad

Figure 43 Body Build Scale Scource: Douty (1968:28)

Douty concluded, however, that the system would have to go further and the height would have to be added in order to make a full body index.



	1 **Bad**	2 **Poor**	3 **Average**	4 **Good**	5 **Excellent**
Head	Markedly forward	Noticeably forward	Slightly forward	Less erect	Up
Shoulder	Markedly slumped	Noticeably slumped	Slightly slumped	Up or rounded	Up
Abdomen	Markedly prominent	Somewhat prominent	Rounded	Is just not flat	Flat
Back	Markedly curved	Curve obvious	Noticeably curved	Slightly forward	Curve within normal limits
Knees	Markedly light, legs form S curve	Tight	Tense	Slightly tense	Flexed
Balance	On toes or heels	On toes or heals	Off	Slightly off	Body over arches
Shoulder	Markedly curves	Curves	Slightly curves	Nearly level	Level
Legs	Markedly Irregular	Irregular	Relatively straight	Straight	Straight

Figure 44 Posture Scale Scource: Douty (1968:28)

This method of figure and posture analysis was an interesting approach to objectively analysing the figure. However, a significant number of the descriptive terms appear to be value judgements, which could have limitations on the objectivity.

3.9 REVIEW OF SOMATOMETRY IN PATTERN GENERATION FOR WOVEN FABRICS

Somatometry has been used in a number of research projects to assist in the development of models for pattern generation.

3.9.1 Graphic Somatometry

The graphic somatometry method of woven pattern alteration was developed by Brinson (1977), based upon Douty's (1968) method of analysing body form. Graphic somatometry is a method of pattern alteration and uses a combination of angles, which are determined from the silhouette photographs of the body. Graphic somatometry has been presented as a simple and rapid method to quantify the spatial relationship between pairs of circumferences on the three-dimensional body and to transfer these relationships to a flat pattern. It is difficult to quantify these relationships using traditional methods of measuring the body and subsequently to transfer them to the flat pattern (Heisey et al 1986:115).

3.9.2 Farrell-Beck and Pouliot

Farrell-Beck and Pouliot (1983) studied the graphic somatometry method of pattern alteration as part of their research at the College of Home Economics, Iowa State University, USA. They altered pants (trousers) using measurements of body length and circumference with the addition of body angles and proportions as a basis for developing seamlines and waist darts. Primarily the body angles were used to determine the slope of the centre front and back seam and the waist dart size. Cubic splines were used to measure the contours and an approximation of the lower crutch was calculated through quadratic interpolation.

This graphic somatometry method was compared with a traditional method. The results showed that the former was preferred for front waist placement, dart size, back crutch and for the horizontal grain. However, it was found that the fit obtained by the two methods was equal. It was also stated that, although the cubic spline analysis worked well, the quadratic interpolation was less successful in describing the lower crutch area. It concluded that further development was needed to perfect the front and back crutch.

3.9.3 Heisey and Others

Heisey developed a more sophisticated method for interpreting the relationship of the somatograph to the garment pattern, based on a geometric foundation. The mathematical foundation used equations that define the relationship between the cone and its flat pattern. Angles are used to alter fitting devices so that the circumferences are accurately distributed in relation to each other. Heisey et al (1986:116) used the term *fitting device* to refer to the use of any dart, seam, flare, gather and tuck etc. The fitting device removes or controls the buckling of fabric caused by the surface of the garment bending in more than one direction and controls the angle of the grain line when the surface bends in one or more directions. It was attested that the three-dimensional form of portions of many garments could be modelled as a truncated cone or part of several cones. For any portion that can be modelled as a cone, a direct geometric relationship exists between the garment and its flat pattern.

It was concluded that the conical model appeared to be valid for the lower half of the bodice and the darted areas of the skirt and pants. It was not entirely satisfactory for any area in which the garment must curve in more than one dimension, for example the side seams in skirts or pants and possibly the shoulder area of the bodice.

3.9.4 Gazzuolo, Delong and Bye

A number of researchers have used a combination of photographic, anthropometric data and somatometry to generate pattern dimensions and alteration techniques. Gazzuolo et al (1992) tried to establish a method to predict pattern angles from photographic measurements. Pattern dimensions were determined using a series of planar measuring devices on a non-woven textile marked with a grid and draped on the subject after reference points had been marked on the body. Pattern dimensions from the body reference points were then marked on the planar device as this was felt to give a more accurate representation of the body surface than traditional measurement techniques. The resulting pattern graph was said to closely approximate the path of the garment plane and more accurately represent the dimensions of a conventional close fitting basic pattern. Further research was required to apply this methodology to the whole body.

3.9.5 Shen and Huck

Shen and Huck (1993) also used somatographic and physical data to develop a more accurate fit model based on angles for the construction of a basic bodice pattern, again further work was needed to encompass adult male, female and child body forms.

3.9.6 Somatometry Summary

The principal of using somatometry has potential, as a method for pattern analysis and development for stretch performancewear. However, to date pattern development using somatographic and physical data has only been used to generate and alter patterns for woven fabrics and not stretch fabrics.

Analysis of the fit of garment pattern profiles based on both empirical and mathematical foundations is valid. The use of graphic somatometry and applied geometrical equations is an interesting concept. However, this particular method of applying angles in pattern generation would be difficult to apply in developing a block pattern for stretch fabric as the method is directed towards dart shaping in woven fabrics to contour the body.

3.10 REVIEW OF PATTERN GENERATION METHODS FOR KNIT STRETCH FABRICS

Garments constructed out of woven non-stretch fabric require ease, which is the allowance of a certain amount of fabric on a block pattern to accommodate movements like sitting down, or involuntary movement such as breathing. Darts are also used to contour the fabric around the body form smoothly without the fabric buckling.

Patterns for stretch fabrics have been produced by taking block patterns for woven fabrics which are then modified by removing ease allowance and darts and then proportionately reducing the patterns horizontally and vertically. When a stretch pattern is constructed (using a front bodice as an example) the dart is manipulated, opening the bust area. The area of the dart suppression is redistributed by a reduction between the sides, the neck and the shoulder. When a multiplicity of research and technical information is available on pattern generation for non-stretch fabrics, it is frustrating that there is so little on patterns for stretch fabrics. Only a few studies into modifying patterns for contoured garments based on the stretch characteristics of stretch knit fabrics have been published.

3.10.1 Ziegert and Keil

Ziegert and Keil (1988) researched into establishing a flexible and economical system for designing a well-fitting body contouring garment for knit fabrics containing elastane. The garment pattern, a sleeveless leotard, was constructed in three stages and to avoid confusion each stage of the pattern was given a specific definition, the 'Original pattern', the 'Modified pattern' and the 'Stretch pattern'.

Stage 1. The *original* pattern was produced by first taking a basic pattern for woven fabric.

Stage 2. The *modified* pattern removed the body ease from the basic pattern (see Figure 45) following procedures outlined by Gioello (1979) and Kopp, Rolfo and Zelin (1965) in their discussion on body ease and pattern development. The pattern was then further modified by redistributing the body shaping elements. The authors then referred the reader to Bray (1964) on dart shaping for body contouring garments: "*The back shoulder was realigned at the armhole and the front shoulder dart was redistributed so one-third was transferred to the neckline and two-thirds to the armhole.*" The side seams at the waist were reduced by 75% of the original waist dart. The remaining "*25% was retained to allow for body movement, avoid fabric distortion, and provide for the best fit. The torso was lengthened 3.1 cm (1¼") at the back hip line to accommodate extreme vertical body movement. The neck was lowered and the leg openings for the leotard were developed from the pant. The front crotch was slashed and pivoted to produce the typical strait centre front line.*" (Ziegert and Keil 1988:58)

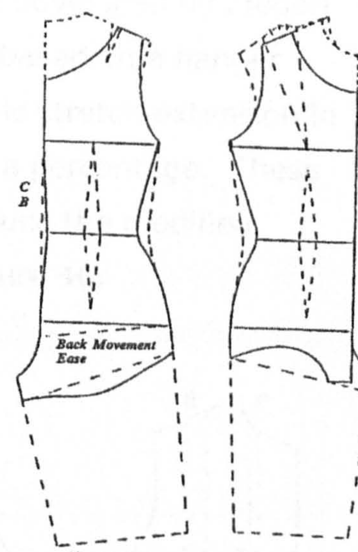


Figure 45 - Lowered Neckline, Dart realignment, Crutch and Leg Development. Ziegert and Keil (1988:59)

The modified pattern is a transitional pattern profile and suitable neither for a basic woven pattern nor a stretch pattern. It is suggested that in comparison to the original pattern the modified pattern was narrower and shorter even though the back was lengthened. They also stated that: "*The development of a modified pattern is a logical step in the process of making a pattern for body contouring apparel.*" (Ziegert and Keil: 58)

Stage 3. The *stretch* pattern was produced by drawing grid lines, similar to those used in pattern grading, for increasing or reducing pattern sizes. The pattern was then reduced in size using a reduction factor. The amount and distribution of the reduction factor was applied using the horizontal and vertical grid lines.

The reduction factor was calculated using the method developed by Ziegert and Keil (1988:56) of measuring fabric stretchability based on a hanger load test, which is outlined in Section 2.6.6. The fabric stretch extension in both the wale and course direction was expressed as a percentage. These measurements were then used to proportionately reduce the modified pattern horizontally and vertically as illustrated in Figure 46.

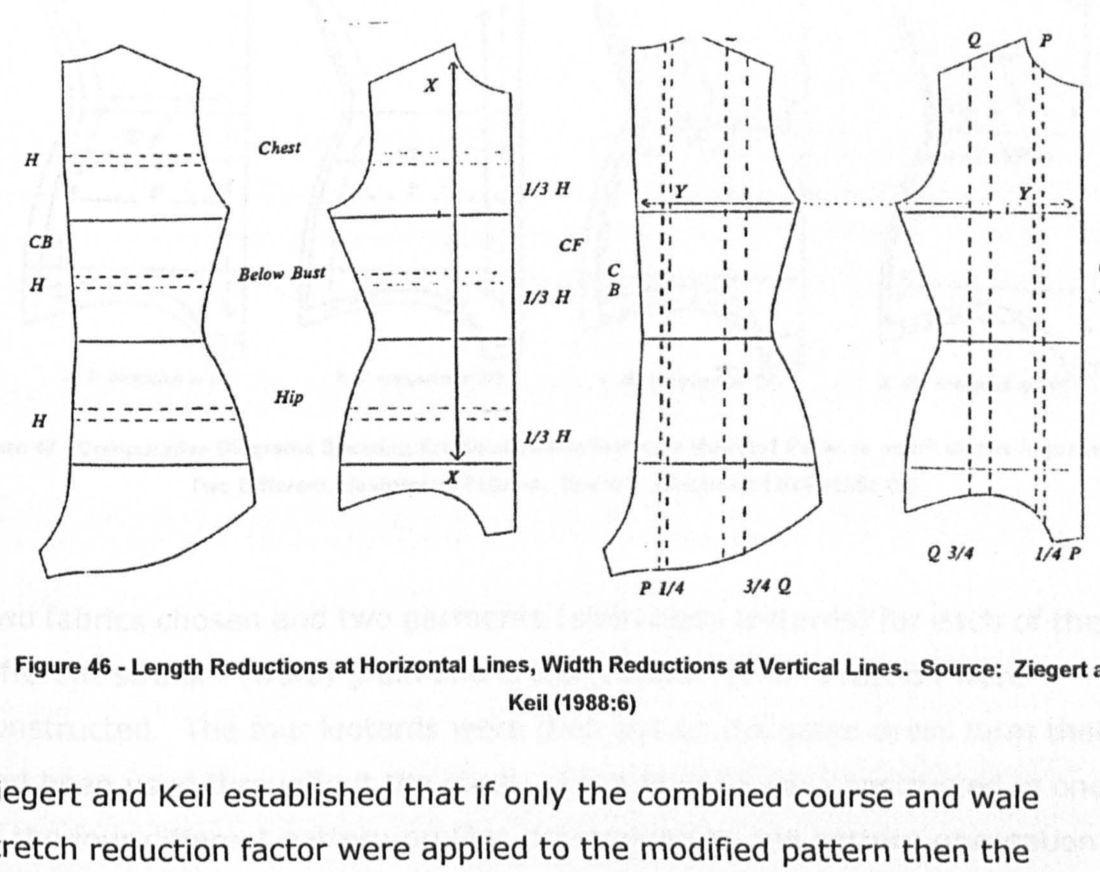


Figure 46 - Length Reductions at Horizontal Lines, Width Reductions at Vertical Lines. Source: Ziegert and Keil (1988:6)

Ziegert and Keil established that if only the combined course and wale stretch reduction factor were applied to the modified pattern then the resultant garments would have inconsistent contour shape fit models. The pattern orientation on either the course or wale grain line of the fabric would also have an effect on the shape of the pattern profile because of the different course wale stretch factors. Therefore, the modified pattern would serve two purposes, one for the application of the fabric stretch reduction factor to produce the individual stretch pattern profile and the other as a means of graphically comparing the effects on the pattern profiles as different stretch reduction factors were applied. Figure 47 illustrates the front modified pattern profile for comparison with the stretch pattern profiles, all of which are aligned along the waist and at the centre front. Bold and dotted lines with arrows at each end indicate the grain direction and correspond to the bold and dotted outlines of the pattern profile.

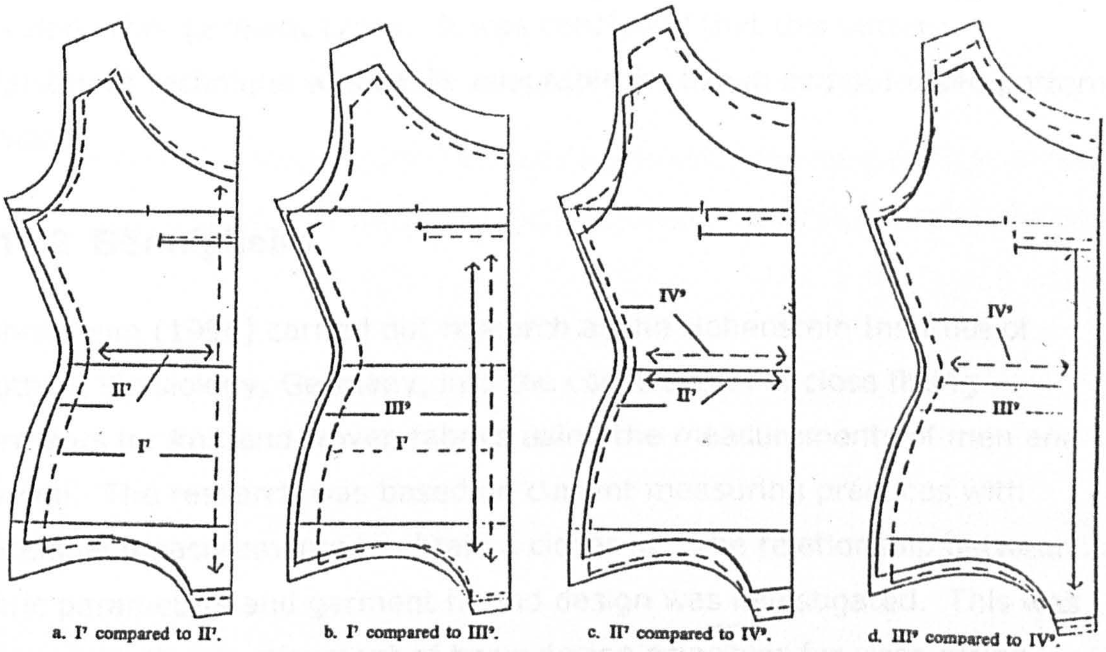


Figure 47 - Comparative Diagrams Showing the Relationship Between Modified Patterns and Patterns Adjusted for Two Different Elastomeric Fabrics. Source: Ziegert and Keil (1988:62)

Two fabrics chosen and two garments (sleeveless leotards) for each of the different straight (wale) grain and cross (course) grain direction were constructed. The four leotards were then put on the same dress form that had been used throughout the study. Each leotard was constructed in one of the four different pattern profiles determined by the pattern orientation on the fabric. The leotards were then assessed by a panel of design professionals, using set criteria, to ascertain the quality of fit. They concluded that despite the differences in pattern profile and fabric properties the resultant smooth fit and the alignment of body landmarks on all the leotards was essentially the same. The four leotards were assessed on live models; they showed no movement restraints and demonstrated the same fit characteristics.

It was concluded that further research was required into structure and weight of elastane fibres and fabrics with elastane, stretch, stress testing and comfort properties. It would also be useful to study the optical effects of fabric orientation on the body contours, for insight into the use of grain direction in stretch garment design. It was suggested that the system was appropriate for the classroom and design studio and could be used to develop other garment types. It was concluded that this pattern adjustment technique was easily adaptable for use in computerised pattern grading.

3.10.2 Bönnigheim

Bönnigheim (1996) carried out research at the Hohenstein Institute of Clothing Physiology, Germany, into the construction of close fitting garments for knit and woven fabrics using the measurements of men and women. The research was based on current measuring practices with additional measurements to obtain a closer fit. The relationship between fabric parameters and garment fit and design was investigated. This was followed by the development of basic design principles for close fitting garments, for example bodices and leggings for computerised pattern development and grading.

3.10.3 Chun and Hue

Chun and Hue (1998) at Yonsei University, Seoul, Korea, developed a bodice pattern modification system, which was based on stretch rate of knit fabric. Nine fabrics of different construction and stretch parameters were used in the study. Six basic patterns were modified to accommodate a different stretch rate which were 0%, 30%, 40%, 50%, 60% and 70% from the basic pattern, which had been modified to six different stretch rates. Six sleeveless shirts were then constructed in each of the nine different fabrics using the modified block patterns. The basic bodice was then evaluated, based on the parameters of each fabric. Results indicated that fabrics with a high stretch rate in the course direction needed minimal reduction to have an appropriate garment fit. The evaluating panel concurred with the findings and the consensus was that the method would benefit students and industry and that the method could be applied in computerised pattern grading.

3.10.4 Kirstein, Krzywinski and Rödel

Kirstein, Krzywinski and Rödel (1999) from the Institute of Textile and Clothing Technology, Dresden, Germany, researched pattern construction for close fitting garments such as men's underwear. The relationship between pattern construction and fabric parameters was examined. It was found that pattern construction for elastic fabrics usually reduces the girth measurement, so that the pattern measurement is smaller than the body. The stretch properties of the fabric were found to influence the garment fit. In addition to this, it was suggested that consideration must be given to the dimensional changes that occur in material as a result of washing. They ascertained that the size of a close fitting garment must be adjusted exactly to the human body and still offer optimal comfort and freedom of movement.

Difficulties were encountered in obtaining garments of comparable fit (for the designated size) for evaluation. When comparing the size and fit of men's underwear manufactured by several different companies, it was found that for the same fabric quality and size designation there were length and girth deviations of up to twenty-five percent. As different countries and manufacturers have developed their own measurement specifications for size charts, it is not possible to make comparison of similar garments from different countries. Official measurement charts, specifically those for men, were largely based on outdated anthropometric surveys. The charts referred to measurements for outerwear because there were no official measurement charts for close fitting body contouring garments or underwear. This necessitated the implementation of a standardised sizing system containing those body measurements required for men's underwear.

In this research they used both uniaxial and biaxial stress strain test methods to record the fabric tensile strength. The fabric was stretched uniaxially and the sample to be measured was clamped on two sides and stretched to the limit of extension while the tensile forces were recorded. This method was found to be practicable and gave information on the effects of fabric behaviour in a garment when being worn with the fabric stretched transversely.

Biaxial stress forces came into play during movement, for example, at the knee and elbows. Therefore, a method for determining biaxial strain to replicate this was developed. The test device clamped the fabric sample on four sides and was then extended equally in both directions. The sample was extended without regard to any difference there might be in the degree of directional stretch. It was recognised that the expense of this equipment was prohibitive to the test method being widely adopted.

The analysis of fabric stretch properties showed a length contraction perpendicular to the direction in which the fabric is being stretched. It was found that in underwear the fabric mainly stretched around the girth and as a consequence the garment length was reduced. It was concluded that optimal garment comfort would be obtained with the fabric stretched around the girth.

An algorithm was developed for men's knitted underwear based on body measurements and fabric extension properties. The CAD system GRAFIS generated the basic patterns and model variants, which were then made up in different fabrics. The garments were assessed in terms of fit and it was concluded that the developed construction rules were an efficient way of meeting high fit demands. It was attested that this system would enable manufacturers to reduce the time needed for changes to designs and fabrics and at the same time optimise the quality of fit.

3.10.5 Aldrich 'Metric Pattern Cutting'

Aldrich (1997:159-166) outlines constructing blocks for close fitting body shapes (see Figure 48). The pattern profile for the body section is the same front and back for the sleeve and torso with the exception of the neck where the front is lower than the back. The sleeve measurement can be of a 'straight arm' because the fabric will stretch to allow arm movement. The leggings have a conventional trouser body rise and seat angle shape. Aldrich states that the blocks are smaller than the body to accommodate fabric stretch; some adjustment in the horizontal may be required to allow for the stretch and relaxation of different fabrics. In this text, pattern reduction relating to fabric stretch and relaxation is mentioned but without any explanation.

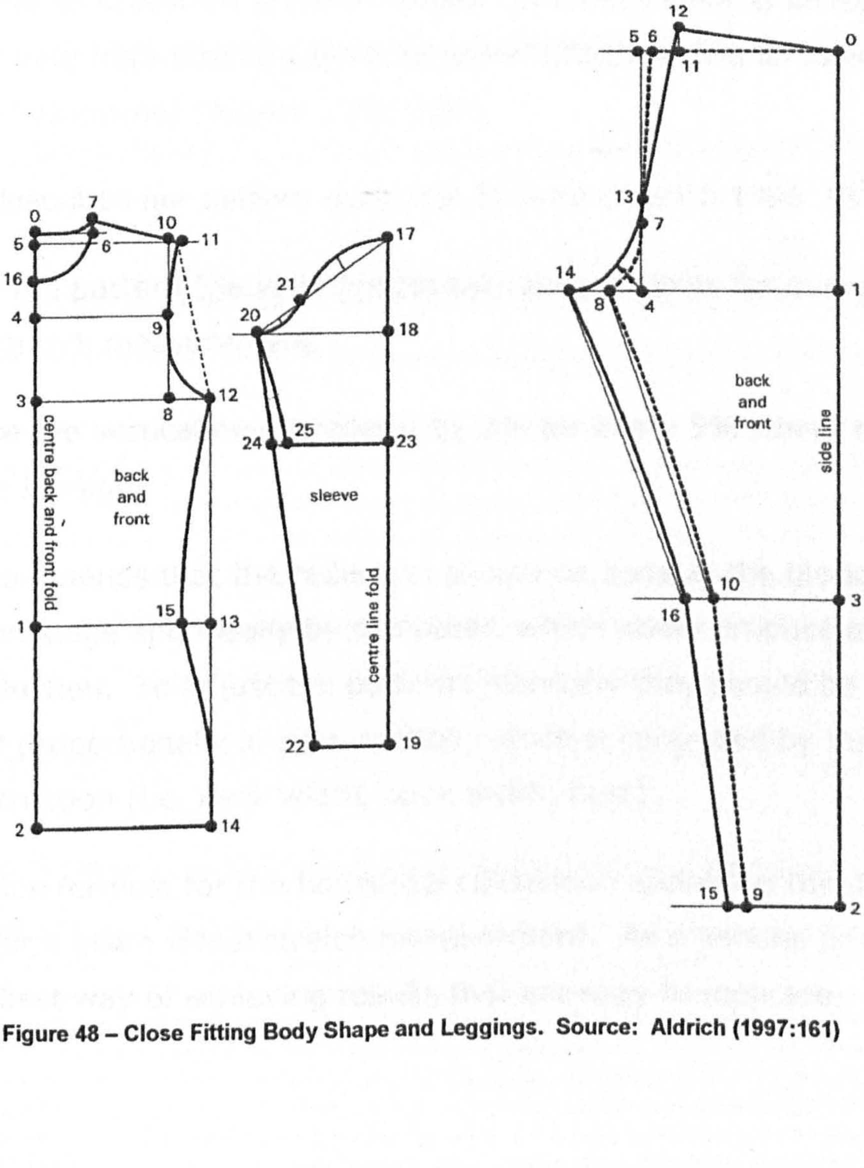


Figure 48 – Close Fitting Body Shape and Leggings. Source: Aldrich (1997:161)

3.10.6 Aldrich 'Fabric Form and Flat Pattern Cutting'

Her later book 'Fabric Form and Flat Pattern Cutting' (Aldrich 1996) introduces a method of pattern reduction, quantifying degree of stretch based on a method that has already been outlined in section 2.6.3.

She details a method for constructing three close fitting blocks for torso and arms. The pattern profile is the same front and back with the exception of the front neck, which is lower than the back. The three blocks have been drafted to accommodate a broad range of stretch extension, although some fabrics would require the blocks to be further modified. It is explained that 'thick' fabrics and those with low recovery rates need little horizontal reduction. Fabrics that only stretch in one direction require more vertical ease allowance. The first two blocks were drafted for fabrics with a basic visual stretch rating of 3-5 (9.5%-30%) which covers the majority of close fitting garments in fashion product ranges. The third block is an example drafted for very high-stretch garments (over 50%) which is suitable for lingerie and swimwear (Aldrich 1996:134).

She then describes her pattern reduction formula (Aldrich 1996:138):

- Reduce the pattern 5% in all horizontal measurements for every 10% visual stretch measurement.
- Increase the vertical measurement by 2% for every 5% where the fabric is under tension.

Aldrich recommends that the reduction should be done at the block construction stage and ideally by computer, which would produce an even pattern reduction. To adjust the patterns manually they should be cut and overlapped proportionally in each section, which is controlled by the initial block construction (i.e. neck width, back width, bust).

The reduction formula for the horizontal calculation quantifies the degree reduction for a given visual stretch measurement. As a general principle this is the best way of achieving results that are easy to replicate.

However, in the formula for increasing the vertical by a percentage where the fabric is "under tension" (Aldrich 1996:138), is not clearly defined. The section on stretch as a whole does not offer a comprehensive understanding of stretch characteristics in relation to the pattern profile, although its aim is to inspire and aid the designer achieve an understanding that:

> The relationship between garment cut and fabric potential is probably the most important feature of present design skills. (Aldrich 1996:5)

This relationship is fundamental for those choosing to work with stretch.

3.10.7 Armstrong

Armstrong has sections in her book pattern construction for different types of stretch garments. Her method for assessing the degree of stretch extension (as previously mentioned in section 2.6.2) has four fabric classifications outlined (1995:472):

- **Stable (firm) knits.** 18% stretch factor on the crosswise grain (5" will stretch to $5\frac{7}{8}$")
- **Moderate-stretch knits.** 25% stretch factor on the crosswise grain (5" will stretch to $6\frac{1}{4}$")
- **Stretchy knits.** 50% stretch factor on the crosswise grain (5" will stretch to $7\frac{1}{2}$")
- **Super stretch knit.** 100% stretch factor on the crosswise and lengthwise grain (5" will stretch to 10" or more)

It is suggested that the 'stretchy knit' and 'super stretch knit' with stretch factors of 50-100% or more, in one or both directions, is suitable for body suits, leotards or maillot.

The stretch patterns were achieved by reducing a block pattern in two stages:

Stage One

Initial reduction of the block pattern was for knits with a stretch factor of 18-25% and the pattern was reduced as illustrated in Figure 49. An extra eighth of an inch was added to all measurements for knits between 25% and 50%.

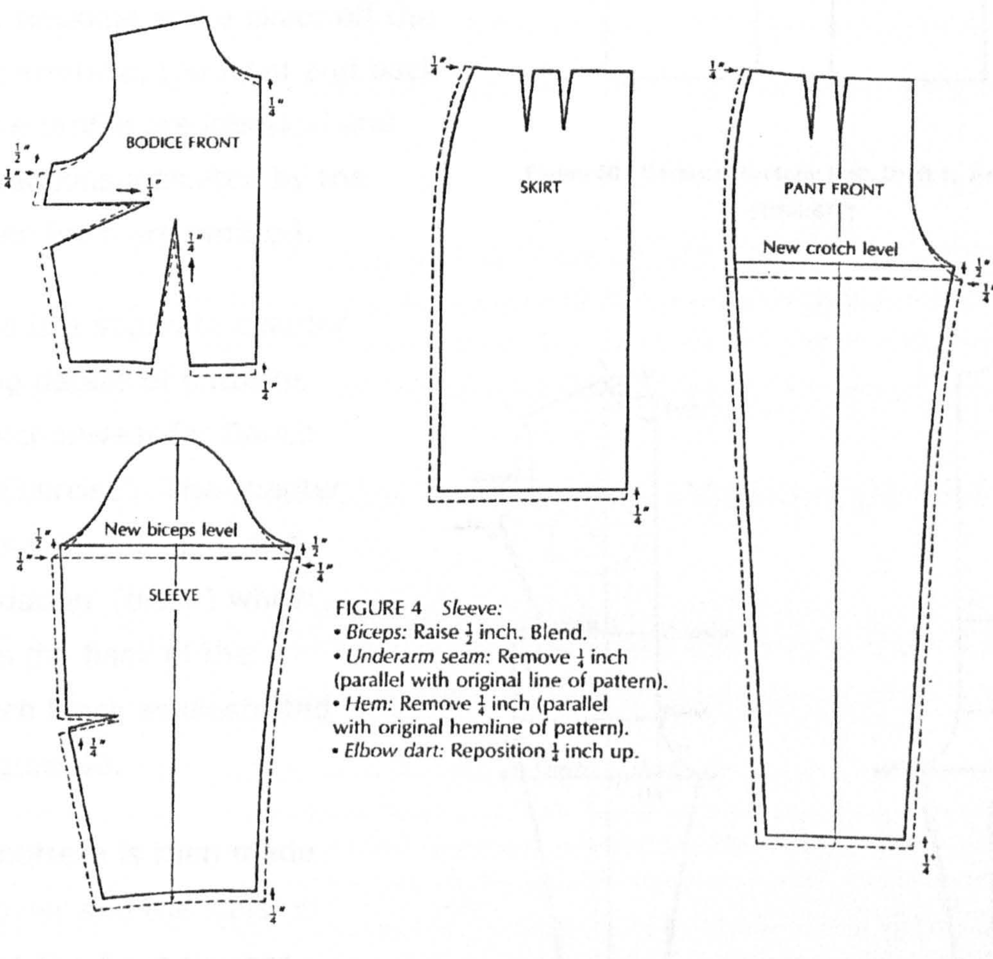


Figure 48 - Initial Reduction of Block Pattern. Source: Armstrong (1995:474)

The measurements are general and it is suggested that additional adjustment at the fitting stage may be required. The broken lines indicate the original patterns. At this stage none of the darts have been removed and the pattern reduction for the back bodice is not illustrated. The removal of ease from the pattern is not an area discussed.

Stage Two

Drafts for a 'stretchy knit' torso and sleeves were made (see Figure 50). The construction method for this pattern is based on the non-existent back bodice. The front and back torso are the same with the exceptions of the front neckline and a sliver off the front armhole, the front and back sleeve profile are identical and the sections indicated by the broken lines are omitted.

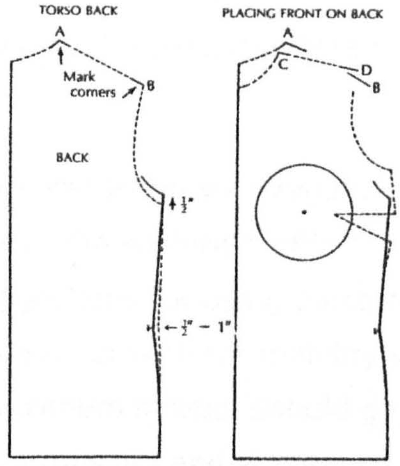


Figure 50 - Dartless Stretchy Knit, Draft 1. Armstrong (1995:475)

There is a separate chapter giving details of patterns for 'Actionwear for Dance and Exercise'. The chapter starts with the 'bodysuit foundation' (block) which takes the back of the stretch block as illustrated in Figure 50.

The pattern is then made narrower and the waist is raised The front trouser block is aligned at the waist as in Figure 51. The back and front are separated but the back may be adjusted at the broken lines if a closer fit is required.

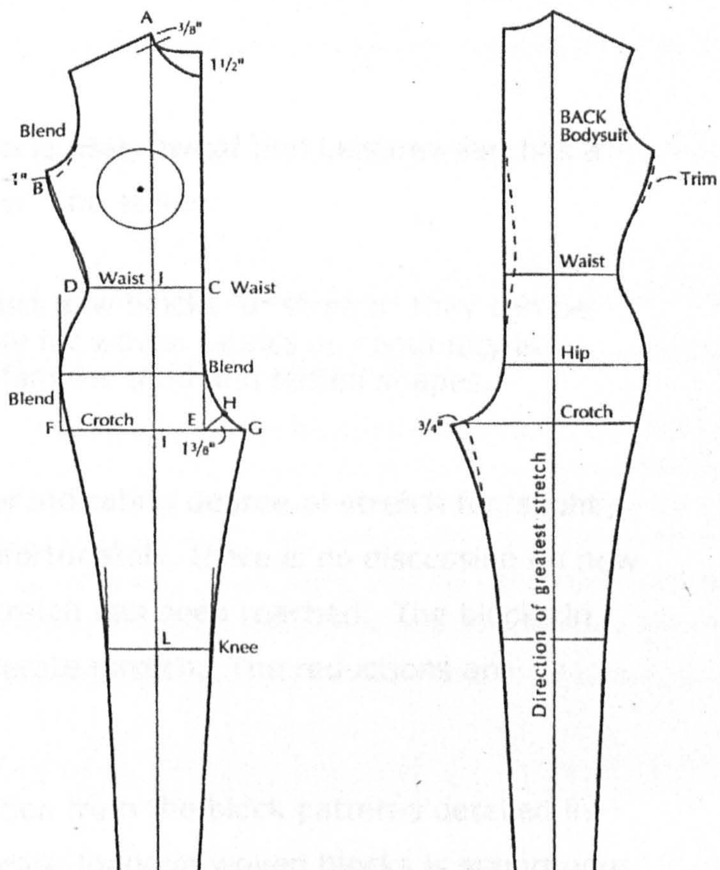


Figure 51 – Body Suit Front and Back Source: Armstrong (1995: 609-610)

Armstrong (1995:611) in the section a 'Method for Correcting [the] Pattern to Improve Fit' suggests that the bodysuit should be made up and the fit tested and pinned to take up looseness or add to the pattern where it is too tight.

The application of the stretch factor in pattern reduction was vague. The stretch characteristics were not utilised to alter the pattern profile geometry. Armstrong's (1995:472-637) suggestions for using pattern orientation to optimise the direction of maximum stretch for mobility were sometimes contradictory. She stated the maximum stretch should go up and down the figure for bodysuits, leotards, jumpsuits and skiwear to allow for maximum mobility and the maximum stretch should encircle the body for dresses, jackets, pants and tops. Later it is stated that for swimwear the greatest stretch also encircles the body and there is obviously no mention of mobility. It is arguable whether it even belongs in this category.

3.10.8 Haggar

Haggar in 'Pattern Cutting for Lingerie, Beachwear and Leisurewear' has a section on blocks for stretch fabrics. She states:

> It is not necessary to construct new blocks for stretch; they can be adapted from blocks originally for woven fabrics as continuity is maintained by working with familiar tried and tested shapes. (1990:216)

A simple stretch guide is offered for indicating degree of stretch for 'slight', 'moderate' and 'super stretch'. Unfortunately, there is no discussion on how to recognise when the degree of stretch has been reached. The blocks in the examples are for slight to moderate stretch. The reductions are doubled for super stretch.

The stretch blocks were an adaptation from the block patterns detailed in her book. She explained that the ease found in woven blocks is superfluous because the stretch replaces the ease. The pattern is reduced mainly widthways and sometimes in the length, but no explanation is offered. The partial or total removal of darts suggested is dependent on the elasticity of the fabric; less stretchy fabrics requiring perhaps a small dart. The illustration in Figure 52 is self-explanatory and demonstrates how the stretch blocks were achieved.

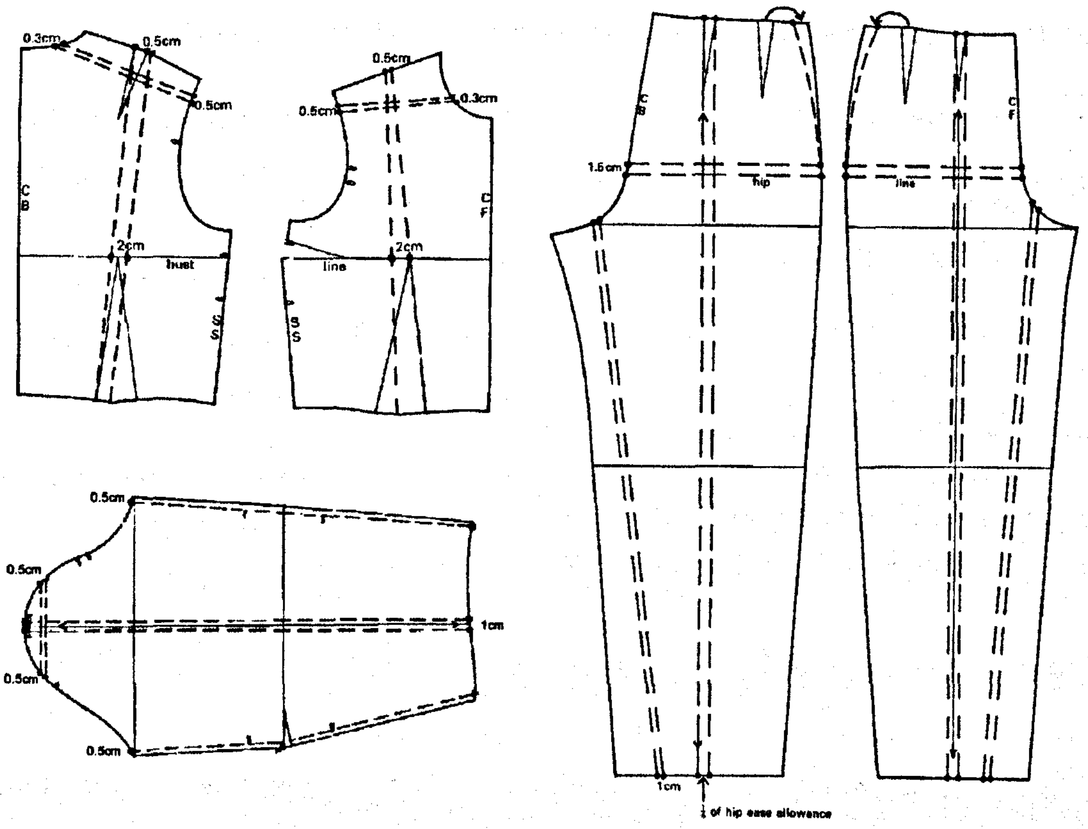


Figure 52 – Blocks for Stretch Fabrics . Source:Haggar (1990:221-225)

Haggar states that consideration must be given to the degree of tightness for the garment to be visually acceptable. She suggests the only way to be sure the patterns will work is to make it up in a similar, less expensive fabric. However, the probability of a different fabric having identical stretch characteristics is questionable. This is a fashion text and although Haggar outlines a comprehensive range of patterns for lingerie, beachwear and leisurewear its use is limited.

3.10.9 Summary Pattern Generation Methods for Knit Stretch Fabrics

The work presented here shows that the various approaches adopted for measuring the degree of stretch for pattern reduction are mainly subjective and this has further highlighted the need for a simple objective test method.

The patterns for stretch fabrics were reduced in size by one method or another and, other than where darts are repositioned, the original pattern profile geometry for a woven fabric was generally retained. The only reference to stretch characteristics altering the geometry of the pattern profile was that of using grid delineation, to reduce horizontal measurements and to reduce or increase vertical measurements.

There seemed to be confusion as to where and when to shorten or lengthen the pattern. There were no observations on the effects of fabric 'grip' or 'tie' points, which restrain the fabric, for example at the crutch, the armpit or a stirrup restraint under the foot.

It was found that the orientation of the pattern on the fabric does effect the shape of the pattern profile. However, there was confusion as to the garment pattern type and which orientation would optimise the direction of greatest stretch for mobility. No reference was made to the implications pattern orientation has for freedom, comfort and fit with regard to the function and aesthetics of the garment.

The interrelationship between the pattern profile geometry and the effect of compression on the body of a garment designed to stretch around the contours of the whole of the body by applying uniform vertical and horizontal reduction alone was not considered. In a conventional pattern that has been modified and simplified for stretch fabric there is usually a contour garment-to-body fit disparity brought about by the rationalised pattern geometry which is approximated into straight lines and fluid curves. If the body is viewed as a series of cylinders that all vary in size, the radius of curvature has an effect on the pressure exerted by the fabric on the body, for example, as the radius towards the wrists and ankles decreases. Radius of curvature is discussed later.

The general consensus appears to be that a block pattern for woven fabric is the logical starting point for developing a block for stretch fabric. However, it is recognised within the industry that it is difficult to extract the original body contouring measurements from those required by the block pattern which include an ease allowance irrespective of the pattern construction procedure (Brunn 1983:98). Therefore, the geometry of an adapted block pattern for woven fabric may not conform to the body contours to generate a dynamic fit for a block pattern for stretch fabrics.

3.11 SUMMARY OF PATTERN GENERATION

The garment industry has attempted to rationalise pattern sizing and these patterns usually conform to a garment size specification, however, women's measurements and sizes are based on surveys carried out nearly half a century ago. Body scanning techniques will effectively reduce the time consuming process of physically gathering anthropometric data for pattern generation. To date industry still relies heavily upon measurement data sets that have emerged through trial and error and unfortunately, the measurements taken gave no indication of the shape and proportions or posture of those measured.

It is the shape, proportion and posture of a person that is important and not the garment size and all drafting systems to a greater or lesser extent make assumptions about posture, body shape and proportions based on measurements. However, conventional pattern drafting co-ordinates are usually based on derived and not direct body measurements. So although many women take the same size there may be a disparity between their body shape, proportions and posture and those assumed by the garment pattern construction co-ordinates. Also manufacturers' sizing systems don't usually state a garment-to-body fit relationship classification expectation related to the individuals fit and comfort preferences which are variable and cannot be ignored as the industry moves towards mass customisation.

Anthropometric somatotyping is a classification system which describes both male and female body shape and composition. Sheldon and fellow collaborators Stevens and Tucker developed somatotyping as a systematic approach to studying personality based on physical data. The terms used in describing body types in the system are Endomorphy, Mesomorphy and Ectomorphy. Three views of the body, the front, back and side, are photographed and the horizontal diameters of the images are measured and used in the somatotyping classification process.

The research of Sheldon and his collaborators was refined by Heath and Carter as "a measure of shape not of size". This is a shorthand way of describing both male and female body types based on body measurements. Their somatochart plots the position of an individual's body shape category and is widely used to classify military personnel and sports participants. The descriptions of typical somatotype sports participants are; the endomorph, a sumo wrestler; the mesomorph, a power athlete such as a javelin or discus thrower; the ectomorph, a ballet dancer, gymnast and marathon runner.

Helen Douty introduced a photographic technique, which drew on Sheldon's body shape classification system. The somatograph and the posturegraph were developed as an aid to figure analysis and design selection for her students. The method divorces the observer from the normal aesthetic view of a person and the optical illusions that can be brought about by the clothed figure. Photographs taken of a subject silhouetted against a graph when viewed give an accurate and impersonal figure proportion and posture for interpretation and evaluation.

Somatometry has been used in a number of research projects to assist in the development of models for pattern generation for woven fabrics. However this approach has not been applied to pattern generation for knit stretch fabric.

Few studies modifying patterns based on the extensibility of stretch knit fabrics have been published. Although various approaches have been adopted for measuring the degree of stretch for pattern reduction, these are mainly subjective and this has further highlighted the need for a simple objective test method.

The consensus appears to be that a block pattern for woven fabric is the logical starting point for developing a block for stretch fabric. Conventional patterns are modified for stretch fabrics without significantly altering the profile geometry in the areas of torso limb relationships and protrusions. These patterns after modification are proportionately reduced horizontally and vertically they are then used for stretch fabrics. The effect of the reduction can increase pressure on the body in smaller garment sizes or in garments where there is a considerable disparity between radii. The implications of this stretch reduction technique on the body were not considered. Patterns may be proportionately reduced in size if appropriate although if the original pattern profile geometry for a conventional pattern is retained, where the profile is rationalised into straight lines and fluid curves, then this can often result in a garment-to-body fit disparity. The fabric stretch characteristics and their impact on the geometry of the pattern profile have not been considered.

It is apparent that adopting a conventional approach to pattern construction using derived pattern drafting co-ordinates, which make assumptions about body shape and proportions and posture (usually a rigid upright stance), will not produce garment of a consistent fit quality. This approach using modified conventional patterns for stretch fabrics, even when some inconsistencies in the garment–to-body relationship can be absorbed within the stretch fabric parameters, still does not produce garments with a consistently good fit quality. Before even attempting to construct a pattern to achieve a desirable fit quality for freedom and comfort it has to be stated that the defining of any garment fit can only be interpretive as it is dependant on the individuals fit preferences and subjective assessment. However, there are four factors that have to be considered, interpreted and defined:

1. The specific posture or movements to be adopted by the body.

2. The proximity of the garment-to-body fit relationship.

3. The factors that promote a quality garment-to-body fit relationship.

4. The undesirable factors that impinge on the quality of the garment-to-body fit relationship.

Conventional pattern drafting techniques need to be reinterpreted from first principals and the body measurement data acquisition should reflect this.

The integrated body measurements and the two-dimensional pattern drafting co-ordinates should reflect accurately the three-dimensional body posture profile. The pattern should be constructed from direct body measurements or a measurement set that is interpreted dynamically to produce garments to fit the shape, proportions and posture of either an individual or a target market segment.

CHAPTER FOUR

FIT FOR MOVEMENT

4.1 INTRODUCTION TO FIT FOR MOVEMENT

The fundamentals for fit are that the design must be appropriate for the situation; the garment must fit well and provide for freedom of movement, enabling the individual to feel comfortable both physiologically and psychologically. There are no hard and fast rules. We are all unique and our perceptions and judgements are based around life's experiences and expectations. The focus of garment fit for movement is ultimately on those areas where joints function multi-axially and, therefore, require special consideration to maximise movement potential and fit quality.

4.2 MOVEMENT ANALYSIS

Kinesiology is the study of human movement. It covers three key areas; the origins of movement in the brain and the central nervous system; the biological processes that activate the nervous system to produce motion; the physical mechanics of motion. The last stage of the process referred to is Kinematics, which is concerned only with describing body movement itself and not the causation or forces impelling movement. Kinematic analysis equips the designer with a deeper understanding of the many complex variations of anatomical movement.

Another area encompassed by Kinesiology is Kinanthropometry. Kinanthropometry defines relationships between body size, shape and composition and human movement performance. One method, the somatochart (outlined in the Chapter 3), can be used to plot the optimum body type category for specific sports. This technique for analysing the contour shape profile of divergent somatotypes, used in conjunction with a posturegraph, can be related to the specific postures adopted during movement to assist pattern development for movement.

To optimise human performance, the application of both quantitative and qualitative kinematic analysis is necessary. In quantitative analysis the performance, or certain aspects of it, are measured. However, quantification of measurements taken under stringently controlled conditions cannot be purely objective; there is always an element of subjectivity in the definition of a body landmark, or the hand tension of the tape during measurement. The quality of fit for comfort and mobility must coincide with a basic understanding of human movement. The qualitative analysis of human movement is an interdisciplinary skill. Knudson and Morrison define qualitative analysis as:

> The systematic observation and introspective judgement of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance. (Knudson and Morrison 1997:4)

This discipline's major objective is to improve the athlete's physical performance. Some of the techniques employed in the qualitative analysis of human movement can be applied successfully by the performancewear designer as part of the overall design strategy.

The way in which an individual assimilates and organises sensory information for interpretation (their perceptual style) does appear to make a difference in qualitative analysis. Dale pointed out that knowledge of the subject under observation is prerequisite by saying: "*We can only see in a picture what our experience permits us to see.*" Knowing how and what to look for is the observatory task. (1984:58)

Pinheiro and Simon (1992) suggest a model of information processing as a useful first step in understanding how perception works in qualitative analysis. A strategy is needed because the observer has information that crosses many disciplines. Good preparation is vital to obtain accurate information related to the movements to be observed. The relevant information needs to be assimilated and prioritised in order to focus on the critical features that will be the target of observation. An appropriate systematic observational strategy needs to be implemented; the flexibility of the approach strategy should be based on the purpose of the analysis. A Gestalt approach for example would build a total picture or feeling about a movement from all sources of information producing a general assessment of that movement.

Barrett (1979) neatly summarises the three components needed in planning an observational strategy:

- deciding what performance variable to observe
- planning how to observe
- knowing what factors influence the ability to observe

A Biochemist, Hudson proposed an approach to quantitative analysis called POSSUM (purpose/observation system of studying and understanding movement) her observational model stresses *"that the purpose MUST be associated with some observable dimensions of movement. These dimensions are the variables that the observer must evaluate visually and may focus at the whole body or somatic level or on the sectional (segmented) level."* (Hudson 1985:19)

The models highlighted have been specifically developed to optimise performance skills in sport. However, the basic concepts can be adapted successfully as part of a garment design strategy.

The systematic observational strategy can assist in identifying the fundamental movement patterns to be accommodated by the garment. These encompass the critical movements that impact on the overall patterns of movement, the posture, body orientation and body segment position.

The position and distance of the observer can vary, depending on the segment of body being the focus of the observation. Some form of shorthand notation is essential for movement analysis and although a number of systems have been developed these have not focused specifically on the needs of the stretch sportswear designer. Deng (1996: 24-47) as part of an investigation of body movements and their relationship to garment design introduced an upper body posture coding notation system.

The basic stick drawing illustrated in Figure 53 is enhanced by the introduction of a body linkage system, which is based on engineering principals and identifies the joint location between body segments. The system also identifies by degrees the placement of body segment along a defined body plane at the point on the path travelled away from the anatomical position.

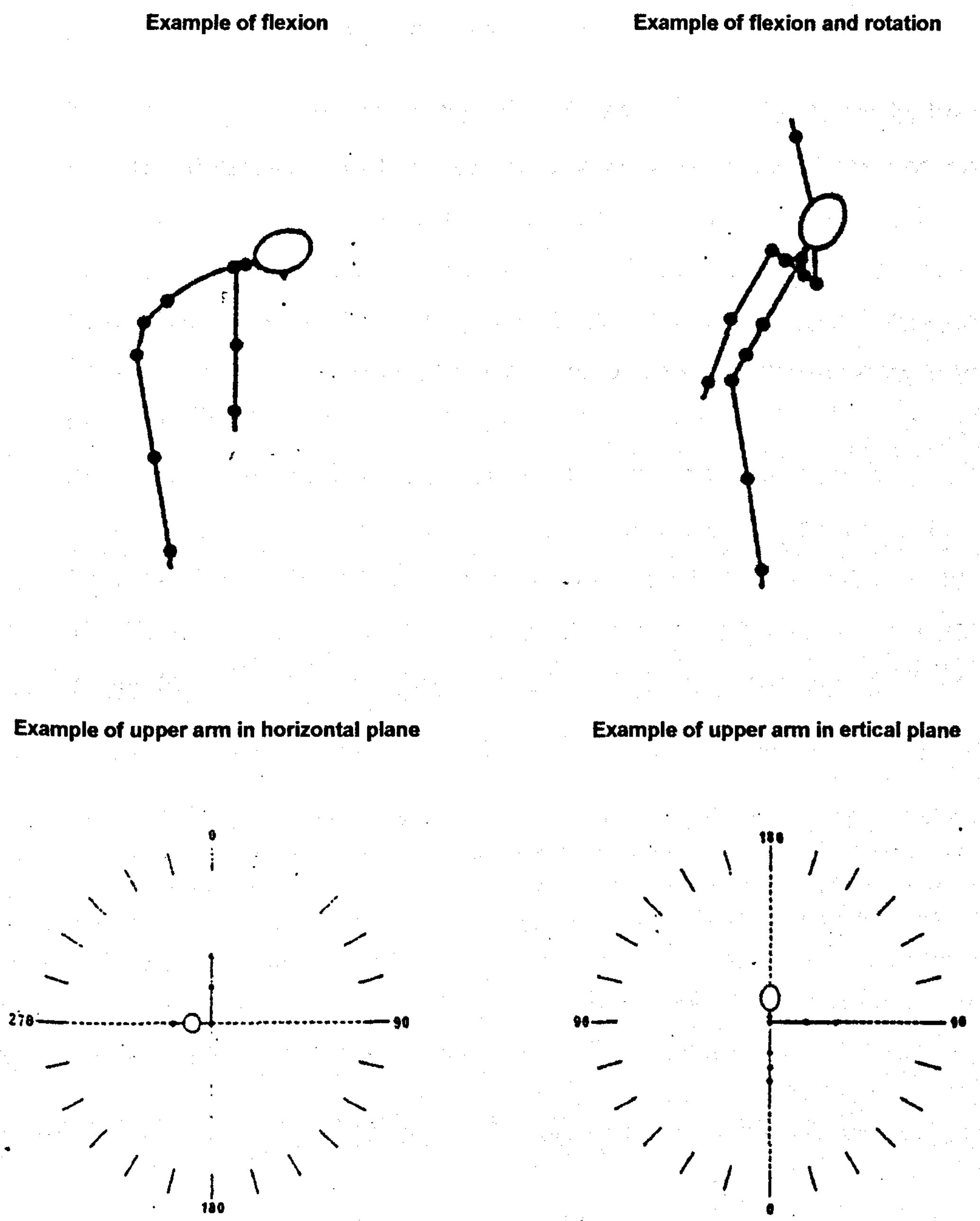


Figure 53- Upper Body Posture coding System Source: Deng (1996: 46-47)

This posture coding system could prove useful to the performancewear designer as it allows a range of movements to be conveyed in simple notation format. Although a notation system is invaluable the documentation of all the nuances of movement would produce a mountain of data, with most of it being irrelevant. Training videos are an excellent tool and they have the advantage that they can be observed repeatedly, viewed in a single frame or in slow motion. Multiple exposure time lapse photography and computer simulation is also useful.

The critical movement features and other variables have to be assimilated into the overall design strategy. The environment should be controlled to minimise distractions and it should be as realistic as possible. The suitability of the garment worn during the analysis needs to be examined, to determine any restrictive elements detrimental to effective analysis. The observer needs to be critically aware of the effect that any physical and psychological factors may have on the requirements for particular activities, including dress codes, written and unwritten. The optical effects on the garment of fit, colour and style can also enhance or limit a defective line. Observation using all cognitive information is an essential step in the design ideation, the decision part of the information processing in qualitative analysis.

Knudson and Morrison (1997:27) suggest that a simple model based on critical features of the movement would reduce observational and analytical demands on the analyst. However, it may increase the demands for preparation of qualitative analysis. Their model (see Figure 54) is based on a closed loop starting with *preparation* followed by *observation, evaluation, intervention* and, if required, closing back to preparation.

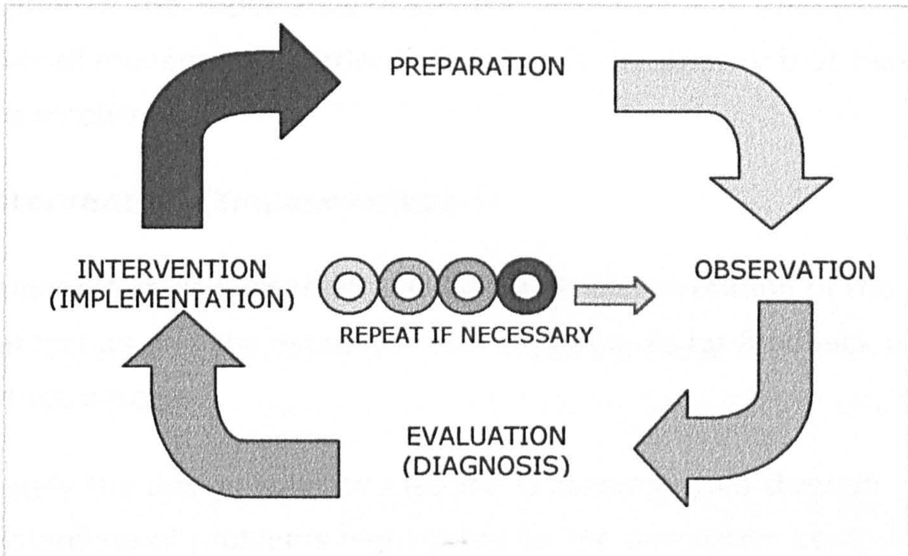


Figure 54 - An Adapted Model of Qualitative Analysis Source: Knudson and Morrison (1997:27)

- **Preparation**

Preparatory information to establish knowledge of the activity should encompass a comprehensive review of literature and graphic material relevant to the movement involved. The perception of the complexities of human movement may be limited by the observer's experience. Interviews with movement practitioners and their relevant associates are vital. The interpretation of movement in a specific sport by an experienced instructor and sports practitioner are invaluable in identifying and prioritising critical factors. An appropriate systematic observational strategy can then be detailed.

- **Observation**

The observational strategy is then implemented in an appropriate situation. The number of observations and the extent of the movements under scrutiny are viewed and documented by the observer from key vantage points.

- **Evaluation**

Evaluation of the importance of specific movements is then essential within the overall movement in order to determine the priority that movement should receive.

- **Intervention (Implementation)**

Implementation of a visual model based on interpretation of the prioritised critical factors and the establishment of principals for feedback maximises the whole process.

Ultimately the design solution ideation is accomplished through understanding of problems highlighted by the perception components of preparation, observation, assimilation of the critical movement features and other variables and, finally, evaluation. Information processing through observation and diagnostic evaluation are two different processes, although they are related and can occur at the same time. Only when all related aspects have been received can the problems be fully identified and prioritised. By separating the tasks the problem can be defined, impelling the decision ideation process towards the solution.

4.3 ANATOMICAL MOVEMENT

Preparatory study focused towards the areas of the anatomy where localised movement has an impact on basic block pattern geometry is an essential step in the pattern design development process.

The human skeleton is a supporting framework of over two hundred bones, with different joints providing the structure of many complex patterns of movement. In simple terms a joint is formed where two bones meet. There are three types of joints which are categorised by their range of mobility. The first are immovable joints, the second are slightly moveable and the third are freely moveable joints.

4.3.1 The Definition of Joints

- **Immovable joints**

These are joints that do not move or that become immovable when bones fuse. This takes place as the body develops and grows, for example in the skull.

- **Slightly moveable**

These are joints with limited movement like those found in the pelvis and the joints at both ends of the clavicle (collarbone).

- **Freely moveable**

Freely moveable joints offer extensive movement, examples are the shoulder and hip. It is this joint type which is of particular interest in this study because freely moveable joints impact on the block pattern profile for comfort and mobility.

The moveable joints can be further classified by the extent of permitted movement as illustrated in Figure 55. Fingers are uniaxial joints as they move principally backwards and forwards and it is the knuckle joint (biaxial) that gives them their sideways motion. The wrist and elbow are biaxial joints because they allow movement on two principal axes. The range of movement at the shoulder is multi-axial and is the joint with the highest degree of freedom (Croney 1980:99, Abernethy et al 1997:46).

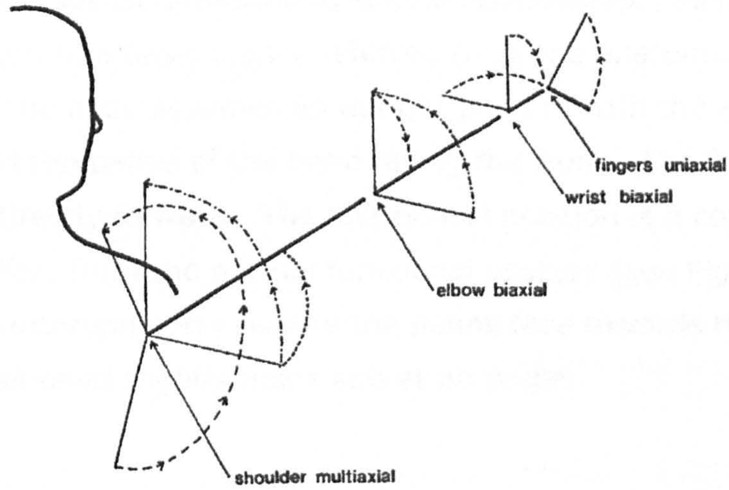


Figure 55 - Joint Movement Range. Source: Croney (1980:99)

4.3.2 Types of Movement

There are two types of movement, voluntary and involuntary. The heart and lungs are an example of involuntary movement because conscious control cannot be exercised over their function. Voluntary movement is the culmination of a series of commands that are initiated by the brain. Muscles are attached to bone by tendons which are tough, fibrous bands of tissue, whilst ligaments consist of strong cords of fibrous tissue which support and hold the articulating surfaces of the joints together. Muscle fibres can contract to between one half and one third of their relaxed length and always act as contractors to pull this well-planned system of levers (muscles, bones and joints) into action.

4.3.3 Movement Description

Watkins (1995:218-225) describes movement in a section of her book, 'Clothing: The Portable Environment', which is a comprehensive and invaluable text for the performancewear designer. Her descriptions of movement are so clear that this thesis has drawn extensively on her work.

4.3.4 Anatomical Posture

As a starting point for communicating spatial relationships, all movement is defined in relation to a basic stance referred to as the *anatomical position*. In this position the body assumes an upright posture with the arms hanging by the sides and the palms of the hand facing the front. The feet are aligned facing directly forward. The anatomical position is a conventional attitude and differs from the normal functional posture (see Figure 55) that is assumed for anthropometry, where the palms face towards the thigh and the feet are positioned slightly apart and at an angle.

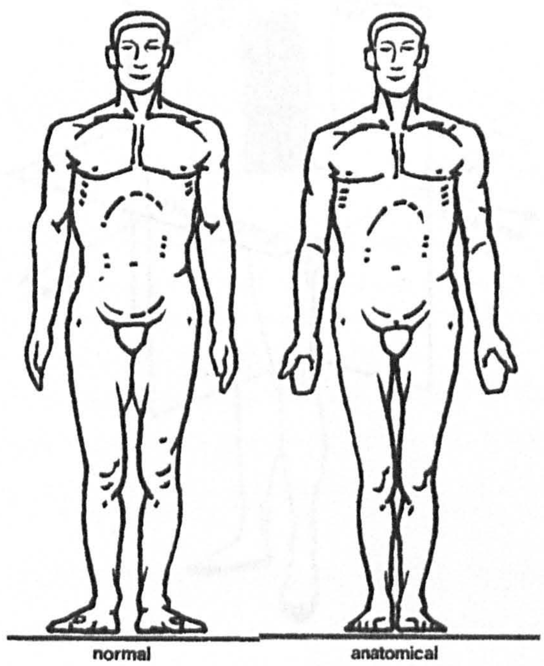


Figure 55 - Normal and Anatomical Position. Source: Croney (1980: 11)

The structure of the body can be considered as a series of moveable segments, which form links between the joints. The relationship of the body segments is always described from the base anatomical position and, therefore, the name of the joint motion remains the same irrespective of whether the body is upside down or horizontal. (Croney 1980, Abernethy et al 1997, Watkins 1995, Heck et al 1965, McClintic 1980).

4.3.5 Body Planes

To aid the description of movement, the body is divided into three bisecting planes and three axes of rotation, all of which are perpendicular to each other. These are illustrated in Figure 57. A plane is a two dimensional area and an axis is a pivotal point on a line between two points. The longitudinal axis passes through the centre of the body from head to foot.

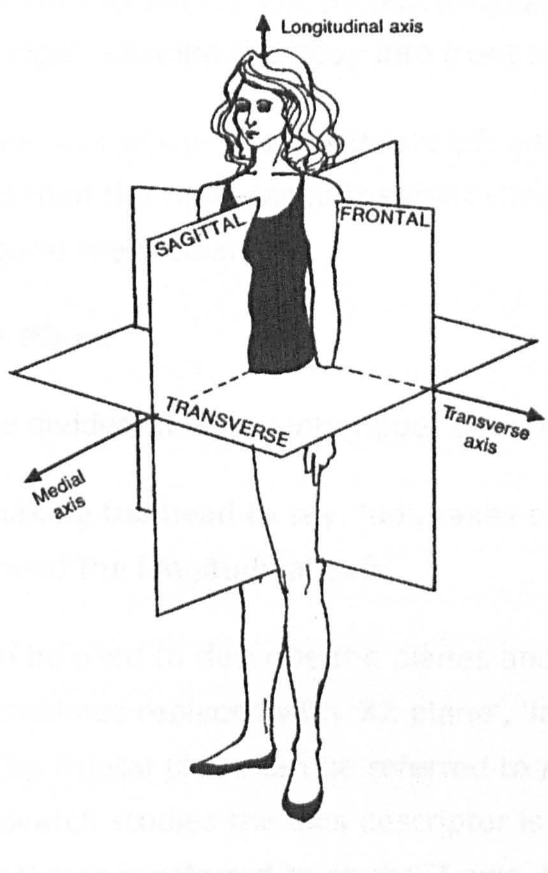


Figure 57 - Planes of Motion of the Body. Source: Watkins (1995:220)

The planes divide the body into three sections left and right, front and back and upper and lower. Movement on any of the three planes takes place in parallel. The axes are the lines or rods which act as a pivot, around which the motion takes place and can be thought of as passing through a joint in a specific direction.

- **The Sagittal Plane**

The *sagittal plane* passes through the *longitudinal axis* from front to back, dividing the body into right and left halves.

When the head nods up and down to say 'yes', movement takes place in the sagittal plane around the transverse axis.

- **The Frontal Plane**

The *frontal plane* (or coronal plane) also passes through the *longitudinal axis* but from left to right, dividing the body into front and back.

The side to side movement of the head, with the left ear gravitating towards the left shoulder and then the right ear to the right shoulder takes place on the frontal plane around the medial axis.

- **The Transverse Plane**

The *transverse plane* divides the body into upper and lower sections.

The movement in shaking the head to say, 'no', takes place in the transverse plane around the longitudinal axis.

Other terms can also be used to describe the planes and axes. The term 'sagittal plane' is sometimes replaced with 'XZ plane', 'lateral plane' or 'horizontal plane'. The frontal plane can be referred to as the coronal plane. In engineering or research studies the axis descriptor is substituted with a letter; the longitudinal axis is referred to as the Z axis, the medial as the X axis and the transverse as the Y axis (Robuck 1968:81).

4.3.6 Body Movement Terminology

The terms used in the field of kinesiology describe basic body segment movements in relation to the anatomical position. To visualise the body movements that occur at the joints, the movement is described in relation to the path travelled away from, or returning to, the anatomical position. This technique for visually referencing movement is firmly attached to the body. The descriptions remain the same irrespective of the adopted attitude of the body, which could be upside down or lying horizontally. The joint motion can also be expressed as an angle between the neutral anatomical position measured by 0°, and a specific point along the path travelled by the particular body segment.

- **Flexion and Extension**

Flexion and extension are forward and backward movements of the body segments pivoting on the transverse axis through the sagittal plane. The body segments in the anatomical position are fully extended. Straightening of the limbs is referred to as extension and as the segment bends this is *flexion* and results in a decreased angle between adjacent body segments at a joint (see Figure 58).

Figure 58 - a) Flexion of the Arm b) Extension of the Arm. Source: Watkins (1995:222)

- **Abduction and Adduction**

The abduction and adduction of the body segments pivot on the medial axis in the frontal plane. *Abduction* is the movement away from the centre line of the body or body part sideways, and *adduction* returns the body segment to the neutral anatomical position (See Figure 59).

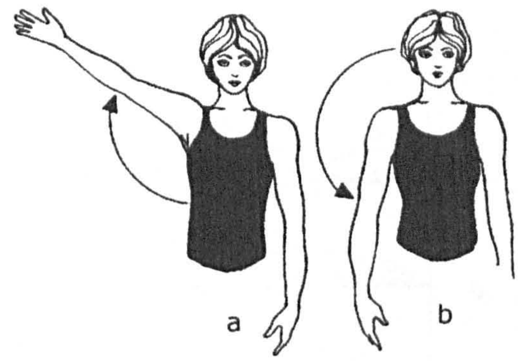


Figure 59 – Movement on the Frontal Plane. a) Abduction of the Arm, b) Adduction of the Arm. Source: Watkins (1995:222

The range of movements is further qualified by the addition of modifiers and prefixes to the basic terms.

- **Lateral and Medial Movement**

The modifier *lateral* indicates that the movement is toward the side. The opposite term *medial* is used to indicate movement towards the midline of the body. Medial and lateral are terms often used in anatomy to indicate the position of a body part towards the middle or the side of the body. When the head or trunk is bent to the side, this is referred to as *lateral flexion* (see Figure 60).

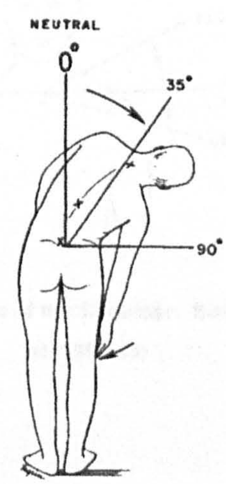


Figure 60 - Lateral Motion. Source: Heck et al (1965:51)

- **Rotation**

Rotation is the movement of a body segment around its own longitudinal axis, and takes place parallel to the transverse plane. Rotation away from the midline of the body is referred to as *lateral rotation,* and the movement towards the midline is *medial rotation*. These movements when carried out by the forearm would be referred to as *supination,* instead of lateral rotation and *pronation* replaces medial rotation (see Figure 61).

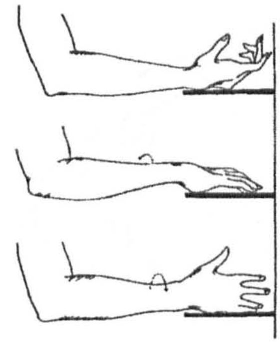


Figure 61 - Rotation of the Forearm: a) Anatomical Position; b) Medial Rotation or Pronation; c) Lateral Rotation or Supination. Source: Watkins (1995:224)

- **Elevation and Depression**

Elevation and depression are among a number of terms used to refer specifically to shoulder movement. The shoulder is capable of a range of varied motion. The most common being the upward or shrugging movement of the shoulders referred to as *elevation* and the opposite or downward movement referred to as *depression* (see Figure 62).

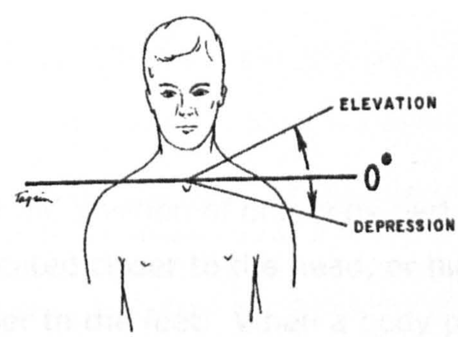


Figure 62 - Motion of the Shoulder. Source: Heck et al (1965:43)

- **The Prefix Hyper**

The prefix *hyper* indicates the movement of a body segment beyond the anatomical position. This prefix is used in combination with extension or adduction, where a joint may extend beyond the anatomical position and assume the reverse angle. When the leg is extended past the side of the body toward the rear this movement would be called *hyperextension* of the leg (see Figure 63).

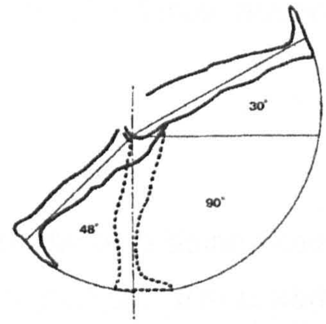


Figure 63 - – Flexion above the Horizontal Line, Extension and Hyperextension behind the Anatomical Position. Source: Croney (1980:106)

- **Anterior and Posterior Movement**

Anterior describes movement towards the front and *posterior* towards the rear. The prefixes *antero* and *postero* are derived from these terms. When the motion is from front to back along the sagittal plane, a body segment is said to be moving *anteroposteriorly(AP).*

- **Superior and Inferior Movement**

Superior and inferior are used to describe the position of one body part relative to another. *Superior* parts are located closer to the head, or higher than *inferior* parts, which are located closer to the feet. When a body part moves to a superior position, it is moving closer to the head.

- **Distal and Proximal Movement**

Distal and proximal identify a reference point in relation to the attachment of a body segment. *Distal* means farther from the attachment point or the midline of the body, while *proximal* means closest to the attachment point. The distal joint of the arm segment would be the wrist and the proximal the shoulder attachment point.

- **Additional Movement Definitions**

Some complex movements require additional terminology to describe those that take place on more than one plane or a series of related movements. The shoulder joint has three planes of travel.

- **Horizontal Abduction**

Horizontal abduction describes the movement of the arm being flexed to the shoulder and then abducted. In *horizontal adduction* the arm is abducted to the shoulder and then adducted horizontally to a forward flexed position. This arm movement can be further qualified in relation to degrees of extension and flexion (see Figure 64) in relation to the neutral anatomical position.

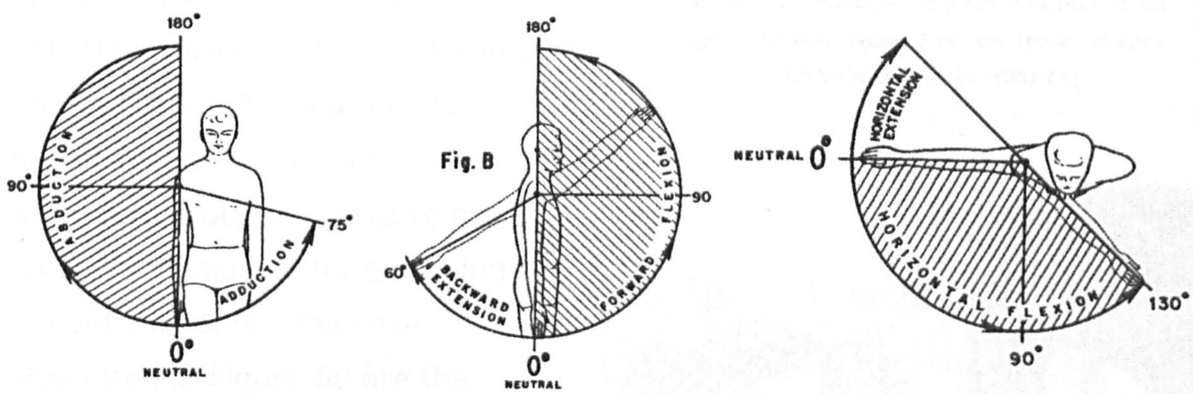


Figure 64 - Motion of the Arm at the Shoulder. Source: Heck et al (1965:33)

- **Circumduction**

Circumduction describes movement in terms of a cone and at the epicentre is the joint. The movement range combines flexion, abduction, extension and adduction. The circular swing of the arm or leg is referred to as *circumduction.*

4.4 DYNAMIC POSTURE

Posture is the alignment of body parts to the physical manner in which the body frame is carried. Posture, in relation to pattern design for fashion, is generally used to describe the static upright position of the body illustration as in basic stances (see Figure 65).

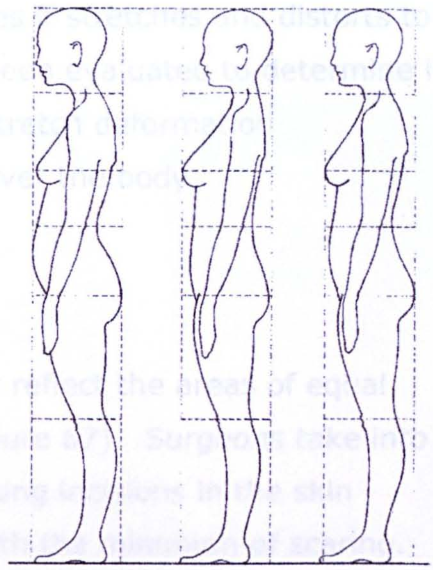


Figure 65 – Posture (from left to right) Curved Spine, Straight Spine, Average Spine. Source: *Taylor and Shoben (1984:63)*

However, for performancewear, posture is used dynamically; different sports are identified with specific postures. The critical effect and frequency of a particular posture has a major impact on the block pattern profile for individual sports. An adaptation of the somatotyping posture graph could be invaluable for analysing dynamic posture. Examples illustrated in Figure 66 are the gymnast with a swayed back (concave) and forward pelvic tilt, the cyclist with a convex back curved over in a riding posture, and the equestrian seated astride the horse.

All of these postures can be accommodated in the pattern profile shape to enhance comfort for the sports participant.

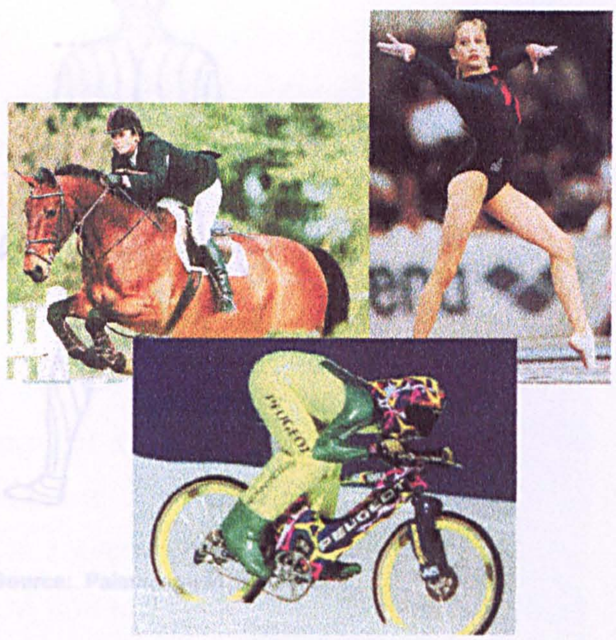


Figure 66 - Examples of Dynamic Posture. Source: World Sports Activewear (1996) The Gymnast (1996),

4.5 SKIN STRETCH

Skin contours the body and as the body moves it stretches and distorts to accommodate movement. Skin stretch has been evaluated to determine if skin stretch behaviour is comparable to the stretch deformation characteristics of fabric when it is stretched over the body.

4.5.1 Langer's Lines

The body can be pictured as having lines that reflect the areas of equal residual stress within the skin at rest (see Figure 67). Surgeons take into account these stress lines when they are making incisions in the skin because wounds cut along these lines heal with the minimum of scaring. They are referred to as cleavage line orientation, or Langer's lines, and give an indication of the orientation of skin stretch (Palastanga et al 1989).

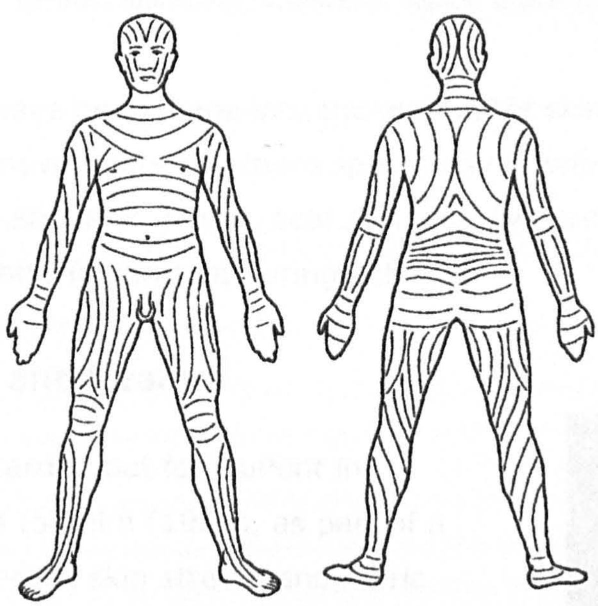


Figure 67- Skin Stretch Orientation. Source: Palastanga et al (1989:41)

4.5.2 Skin Stretch Deformation

The application of grid lines to the skin assists the observation of skin stretch deformation. Figure 68 shows that as the arm is abducted the distortion of the squares becomes more pronounced, particularly in the area around the *armscye*.

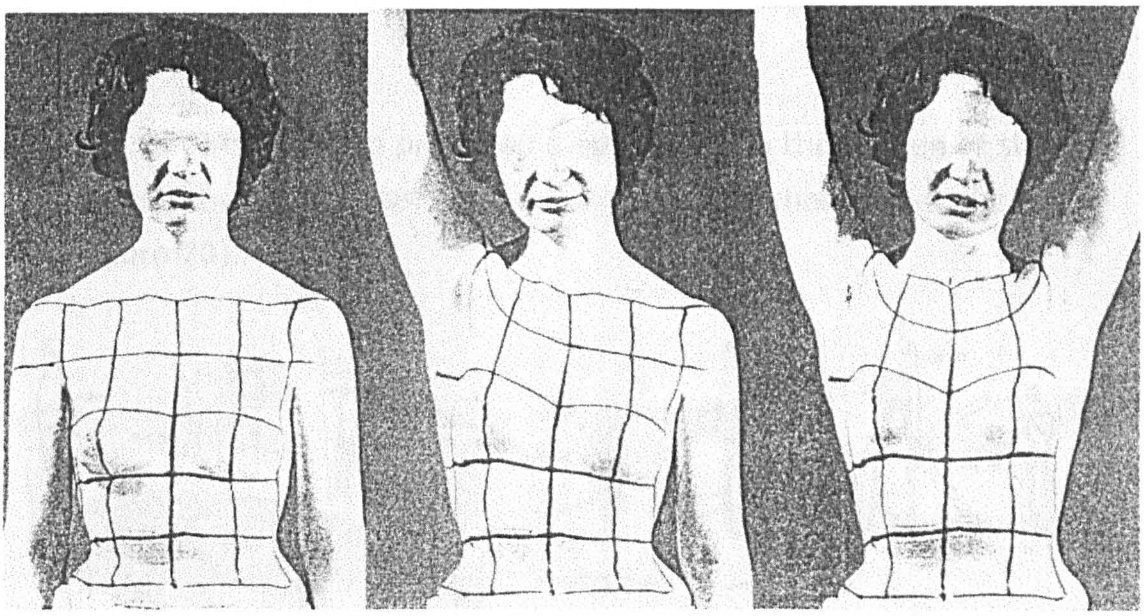


Figure 68 - Skin Stretch Deformation. Source: Bryson (1996:39)

Detailed studies have been made into the amount of skin stretch required by various *body movements and more specifically in critical strain areas* such as the back, shoulder, elbow, seat and knee, where the maximum stress is exerted on the garment during activity.

4.5.3 Kirk Jnr. and Ibrahim

During research carried out for DuPont in America, Kirk and Ibrahim (1966), as part of a larger study, observed skin stretch and fabric stretch, to ascertain a relationship which could then be applied to garments. A series of linear markings (see Figure 69) were drawn on the straight knee and the skin stretch was then measured as the knee moved from straight to bent. It was found that the maximum lateral skin strain occurred at about one inch above the

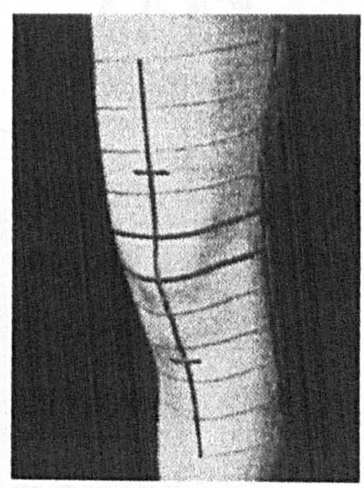


Figure 69 - Skin Stretch Measurement of the Knee. Source: Kirk and Ibrahim (1966:39)

knee and not at the centre. They found that the fabric characteristics over the knee in a stretch garment, when it is restrained around the waist and underneath the foot, perform in a similar way to that of the skin.

4.5.4 Mecheel

Mecheel (1980) and others produced a key, showing the degree of skin stretch brought about by basic movement over the whole body (see Fharnetigure 70).

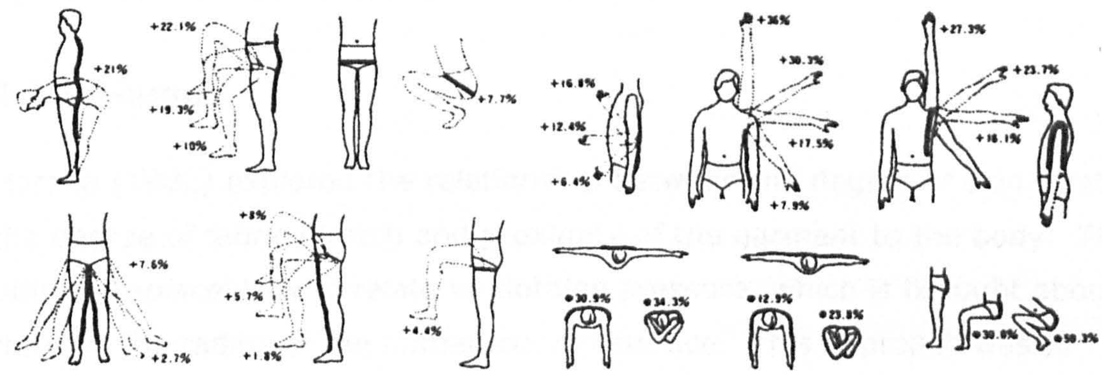


Figure 70 - Movement and Skin Stretch. Source: Harada et al (1982:32)

4.5.5 Harnett

Harnett (1976) suggests that the skin stretch data can be applied to select appropriate fabric construction for different areas of the body to enhance comfort (see Figure 71). The development of fabrics to enhance all aspects of comfort is a growth industry. Tights where the knit structure varies to alter the pressure along the length of the leg are already available in the high street. Further development of this technology could be beneficial for a wide range of applications.

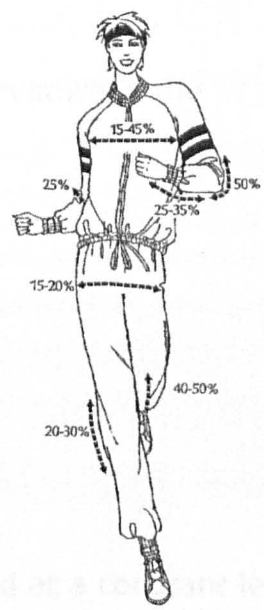


Figure 71 - Stretch Defined for Enhanced Comfort. Source: Harnett (1976:10)

4.6 GARMENT PRESSURE

The application of external pressure is used in the treatment of various medical conditions, typically in the bandaging of venous problems of the leg through to the controlling of very severe scarring on burns victims. The benefits of this research have had an impact in the field of performancewear. Particularly the development of power shorts, which compress the muscles restricting muscle oscillation during movement thereby reducing fatigue, they are said to improve an athlete's performance by 12% (World Sports Activewear 1996:20).

4.6.1 Harada

Harada (1982) explored the relationship between the degree of skin stretch, the degree of fabric stretch and proximity of the garment to the body. They utilised Laplace' Law to relate to clothing pressure, which is brought about through the radius of the human curved surface. This approach was to determine how closely the fabric should conform to the body for optimum comfort levels.

4.6.2 Laplace Law

Laplace' Law relates pressure, tension and radius of curvature in the following way: -

$P = T/\rho$

Where 'P' is the pressure exerted on the body.

'T' is the tension of the fabric, which is constant, and

'ρ' is the radius of the curved surface of the body.

Assuming that the degree of fabric stretch is maintained at a constant level (ideal situation), it is clear that the tension in the fabric will remain constant. The single factor affecting the pressure of the fabric on the body is therefore the radius of the part being covered. The smaller the curve the higher the exerted pressure.

The implication of this is that parts with smaller radii (for example ankles, wrists) require less stretch in the fabric than larger parts (for example torso, arms, legs) to achieve the same pressure and hence 'body hugging power'.

4.6.3 Compression Measurement

When undue pressure is exerted on the body by stretch fabric the effect can cause extreme discomfort. Pressure on the body by the garment, pushes blood away from the surface, which, during activity, becomes sore if the pressure is allowed to remain constant for long periods of time. This can present problems that can be exacerbated by the garment seams particularly over the articulating surfaces where bone is more prominent and also in the areas that are prone to becoming moist and tacky.

The fabric tension and the radius of the human curved surface determine garment pressure. The uniform reduction horizontally and vertically of a conventional modified pattern profile, where the profile is approximated into straight lines and fluid curves, can cause undue pressure on the limbs, particularly the diminishing radii towards the wrists and ankle. However, the authors experience of a wide range of sizes has shown that over a loose range of body sizes varying from 8-14 the problem of garment pressure only becomes significant where the pattern geometry is inappropriate or there is a greater disparity between radii than would usually be expected. However, the problem is exacerbated when uniformly reducing stretch patterns for smaller grade sizes 6 and below particularly for very small children as this can bring about unacceptable pressure on the limbs towards the extremities.

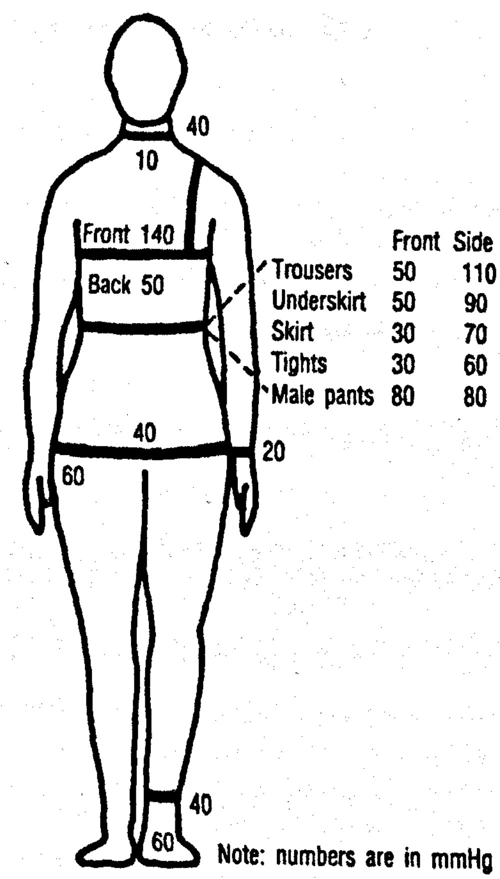
The main body of research for measuring garment pressure is for medical application. Pressure garment studies of the type used to reduce the hypertrophic scarring of burns victims, were undertaken by Giele, Liddiard, Currie and Wood (1985), Ng (1995). Other research into the degree and position of compression needed to attain an optimum effectiveness for compression bandages and elastic stockings was carried out by Fentem and Goddard (1979), Fentem (1986), Filatov (1985).

Research (other than for medical purposes) into the Simulation of garment pressure in wear has been undertaken by Japanese researchers Horino, Kawanishi and Toshimi (1977). The 'Comfort Pressure Evaluation of Men's Socks Using Elastic Optical Fibre' was carried out by Shoh (1998) in Japan.

Studies to ascertain acceptance levels of pressure exerted on specific areas of the body, by the fit of different garments, have been conducted in Britain.

Tests developed by Clulow (Sawbridge 1989) at the Shirley Institute (now re-named BTTG British Textile Technology Group) were carried out to measure acceptable levels of pressure for comfort of waistbands, sock-tops etc (see Figure 72).

The results of both wearer trials and pressure measurements determined optimum pressure levels. It was determined that for the side of the body 100mmHg was found acceptable, which was expected as blood pressure is normally 80/110mmHg (80mmHg venous pressure, 110mmHg arterial pressure). Therefore, pressures higher than 150mm would restrict blood flow at the site of the pressure, causing discomfort.



Source: Shirley Institute research by E.E. Clulow

Figure 72 - Optimum Pressure Levels: Source: Sawbridge (1989:7)

4.6.4 Ibrahim

Ibrahim (1968) undertook an investigation into the "Mechanics of Form-Persuasive Garments Based on spandex Fibers" at the Textile Research Laboratory of DuPont in America. The research was to gain an understanding of the functionality of form-persuasive garments in relation to fabric performance parameters, to provide a proper basis for design.

This study looked at the minimum required fabric stretch levels and ascertained that the fabric extension in 'static' wear was a function of relaxed garment hip circumference. It was found that as the garment circumference increased the garment extension in wear decreased. The additional garment extension, brought about when proceeding from standing to a bending position, should be greater than free body expansion.

Earlier work by Kirk and Ibrahim (1966:40) determined that during bending the average hip to hip extension of the body is 17%. It was found that most of the maximum garment extension values were within the average free-body expansion limit. The frictional resistance to fabric slippage determines the maximum stress gradient. Contributing factors are the fabric-body coefficient of friction and the variable pressure dictated by garment stretch power and relative sizing. A comparison between the free body average strain (17%), and the free-body maximum local extension (35%), might be a more useful prediction of maximum fabric strain during bending.

Ibrahim concluded that the unrestrained-body average strain values were a good basis for predicting the maximum extension which a garment is likely to experience in wear.

The next step was to specify fabric stretch for garment extension. This was measured at a *specific load of 5lb/inch-loop*. A *typical load elongation plot* of a tricot form persuasive fabric is shown in Figure 73. The curve exhibits a region of low modulus followed by high modulus.

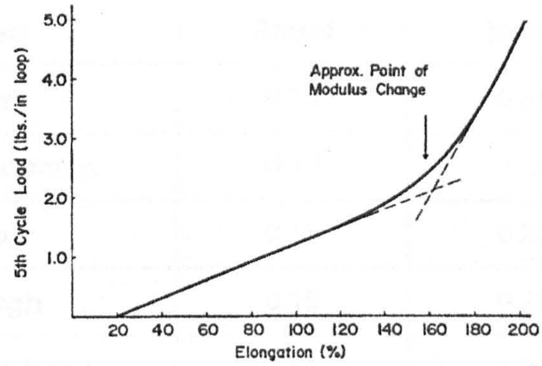


Figure 73 – Load Elongation of Tricot. Source: Ibrahim (1968:957)

In terms of comfort, fabric extension should be within the lower modulus range, so that the *fabric extension at the point of modulus change* should be equal to, or greater than, the maximum strain during mobility. Fabric tension, or its resistance to tensile extension, affects garment control. To assure maximum comfort, provision for fabric stretch should exceed the garments maximum extension and suggests that 20% satisfies this requirement. This gives the available fabric stretch a value which is sufficiently high to ensure that the low modulus (*hugging power*) of the stretch/force curve is utilised. However, this was only suitable for garments of 36" hip or less.

Most foundation garment fabrics are anisotropic, where the stretch *extension is not equal in the horizontal and vertical directions.* The stretch in the wale direction is usually higher. For equal fabric tensions in a garment, the local body curvature will determine the actual local pressure felt by the wearer. For example, *Figure 74 shows that the garment* pressure at the hips is greater than that at the seat when standing, despite the fact that the fabric extends more at the seat and this is due to the smaller radius of curvature of the hips. Conversely, the *increase in garment* pressure through bending is greater at the seat than at the hips because of the higher fabric extension and greater changes in the radius of curvature that occur at the seat. Pressures at the other parts of the body are generally lower than that of the hips.

	Pressure, lb/in^2	
Area	**Stand**	**Bend**
Seat	0.13	0.35
Abdomen	0.10	0.9
Hips	0.18	0.23
Thigh	0.15	0.22
Leg band	0.13	0.29

Figure 74 - Garment Control in Wear (Affect on Body Location) Source: Ibrahim (1968:958

In the standing position the pressure at the abdomen is lower and it also decreases as the subject goes into a bent position because of slight abdominal contraction and curvature changes. Pressure at the leg band is very critical for comfort. The level of band pressure of this particular garment was acceptable, but there were instances in which the leg bands did not have adequate stretch to accommodate body dimensional increases in bending. The local pressure went up as high at 2lb/in^{2,} which was extremely uncomfortable. It is interesting to note that an average, medium size, form-persuasive garment exerts about 60% of the average pressure of a high-support foundation garment on the body. The remaining 40% represents the difference between dictation and persuasion. Ibrahim then went on to identify the body responses to varying support levels in order to subjectively-classify support levels.

Ibrahim concluded that it was doubtful whether local body expansion during movement will ever be matched by local fabric extension, since the fabric of the garment will slip in an effort to reduce the local stress (hence, strain) gradients from point to point at hip level.

Since garment slippage depends on the relative balance of tensile forces and frictional forces of the fabric against the skin, the garment will tend to stretch, rather than slip, as its resistance to stretch is lower than its friction against the skin. Form-persuasive garments usually have an available fabric stretch level which is more than double the 45% unrestrained vertical extension of the body in bending.

The garment pattern orientation is significant in reducing fabric displacement during wear. Providing that the fabric to body frictional and tensile forces, brought about by the fabric stretch power, the garment size and the garment design, maintain the fabric extension within the lower modulus range (which is greater than the maximum body expansion required by mobility) then, by applying the lower fabric power in the vertical direction on the garment, body movement demands will be accommodated through garment extension, rather than by garment slippage. Most of the extension in wear is obtained from the horizontal direction and it was concluded that wale (higher power) or direction of the fabric should be orientated horizontally. The benefit would be a reduction in garment slippage ('ride-up' or 'ride down') relative to the skin during bending.

4.7 GARMENT STRETCH DEMANDS

Stretch in garment design was originally developed for the underwear market. The commercial implications of producing well-designed fabrics and garments to 'slenderise with less constraint' were realised and consequently form persuasive underwear was born! The potential of stretch to enhance comfort in other areas of apparel design became increasingly apparent. To assess the benefits extensive fabric testing and analysis was undertaken.

4.7.1 Kirk Jnr. and Ibrahim

The purpose of the research study conducted by Kirk Jnr. and Ibrahim (1966), in the Textiles Research Laboratory of DuPont in America was to establish preferred stretch level and stretch direction to satisfy comfort demands and to ascertain consumer sensitivity to changes in stretch level.

Kirk Jnr. and Ibrahim compared the effect on garments of available fabric stretch, stretch in use and the optimum stretch orientation for comfort. They examined skin stretch and fabric stretch for a potential relationship. They also noted the relationship between garment size and body size and the effect of garment restraint or grip points.

The relationship of fabric restraint to stretch levels was examined. The level of bi-axial strain that occurred at the knee was then simulated on the Instron, to ascertain the tensile stress at the particular strain. The pressure at the knee was then calculated. The radius of knee curvature (horizontal and vertical) was measured at the same knee bend position as the garment strain was measured. The pressure encountered at the knee was then calculated. They found there was a rapid drop in pressure going from a non-stretch to a stretch fabric until this levelled off at about 25% stretch. The closer fit on the women's slacks meant the pressure drop was greater than the looser fit of the men's slacks.

The general conclusions were:

1. Higher stretch with lower power was always preferred.

2. The preferred stretch range was 25% to 45% depending on end use.

3. The direction of stretch, relative to the body has an important effect on comfort.

Horizontal stretch was preferred for most end uses. It was concluded that for the horizontal stretch slack, the vertical skin demands can be accommodated by slippage, but the horizontal can be met only with horizontal fabric stretch.

It was also found that the horizontal stretch fabric did not deform or bag at the knees as much as the vertical stretch fabric. A higher local strain was observed in the vertical stretch slacks, this was found to be a major contributory factor.

They found that by making the fit closer and increasing the contact or 'tie points' more of the available fabric stretch was used. The findings they suggested would hold true, not just for the Lycra tested, but also for textured 'Dacron' (polyester) and nylon.

4.7.2 Lindberg

Lindberg (1966) a Norwegian textile scientist conducted research into how woven stretch fabrics perform. The purpose was to assess how great the stretchability of the fabric should be to provide reasonable comfort.

He suggests that there are three criteria for a satisfactory stretch garment:

1 The discomfort felt when the garment presses too much against different parts of the body.

2 The extent to which the garment glides and assumes a less aesthetically attractive position.

3 The extent to which the garment adapts itself to the body. (Lindberg 1966:58)

He examined how the garment reacts with regard to the three criteria, which is determined by the interplay between the characteristics of the fabric and garment construction.

The paper discusses what happens between grip or restraint points, which are found on the body at the neck, shoulder, armpits, hips, crutch, arch of the foot, elbow, seat and knee. The research tried to measure the maximum increase in fabric distortion and the distance between various restraint points subject to different body measurements, like crouching.

He found that the fabric never stretched exactly between two points. The grip points in a crouching position, the hips, seat and knees, form a complicated mechanical system. This was observed by drawing a series of circles with a known diameter and which indicated the warp and the weft. When the body was mobilised the circle became elliptical, and the direction of the greatest stretch was indicated by the direction in which the ellipse had its major axis (see Figure 75). It was possible to calculate the amount and direction of stretch at particular points on the garment, where

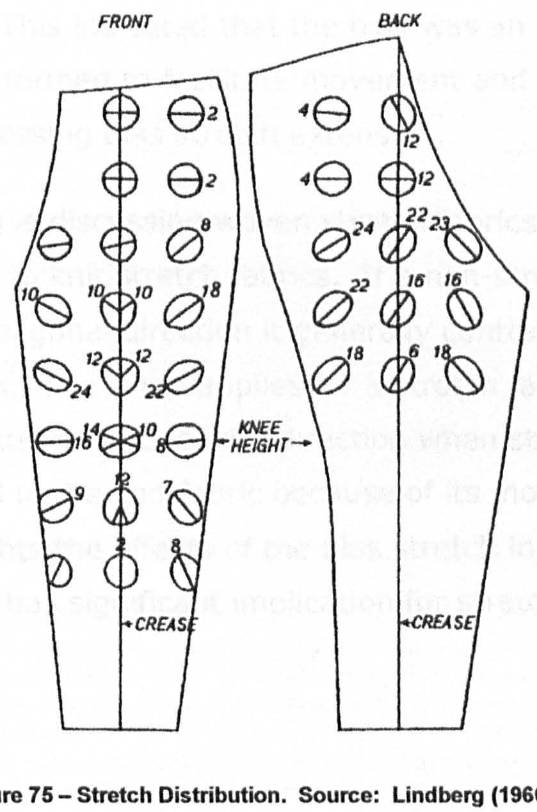


Figure 75 – Stretch Distribution. Source: Lindberg (1966:59)

simultaneous stretch occurs. At right angles the diameter of the circle shows. This method gives a very precise picture of the stretch distribution.

The method was then applied to trousers cut on the conventional grain line in a fabric without stretch and trousers cut on the diagonal or bias in a stretch fabric as illustrated in Figure 76.

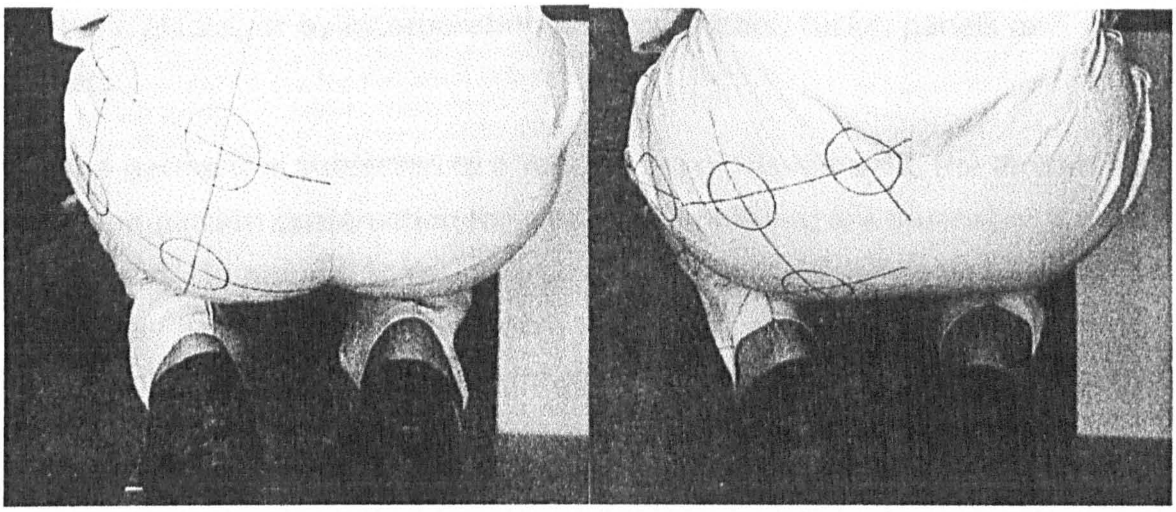


Figure 76 - Conventional and Bias Trousers Orientation, Left on Grain Line, Right on the Bias. Source: Lindberg (1966:60)

It was found that although the trousers cut on the bias were constructed in a stretch fabric, they were more uncomfortable than the conventional non-stretch trousers. This indicated that the bias was an important factor in how the fabric performed to facilitate movement and this emphasised the importance of assessing bias stretch extension.

Although Lindberg is discussing woven stretch fabrics, the findings are equally applicable to knit stretch fabrics. If a non-stretch woven fabric is stretched in one diagonal direction it generally contracts almost as much in the other direction. The same applies for a stretch fabric. The stretch fabric also contracts in the opposite direction when stretched laterally. This effect is enhanced in the knit fabric because of its more mobile structure. This paper highlights the effects of the bias stretch in woven garment design which also has significant implication for stretch contoured pattern profile geometry.

4.8 WOVEN PATTERN AREA COMMENTARIES

The area commentaries highlight some of the ways in which patterns are developed to promote movement. These techniques are for garments constructed in a non-stretch woven fabric. A number of well recognised approaches to achieve greater mobility are either by making the garment proportionally larger, by the addition of fabric to the length or width in strategic places, or by incorporating gathers, pleats, tucks, panels or gussets.

When a garment is subjected to a wide range of movements, the limitations placed on pattern construction for a non-stretch fabric are invariably challenging. In general terms enlarging a garment alone cannot provide adequately for all round mobility and, in some cases, can positively restrict movement. McConville (1986) highlights an example of this in his research into the fit testing of protective clothing. The coverall illustrated in Figure 77 is a Canadian chemical defence overgarment for working in. Although the garment is large enough to fit over another set of clothes, it does not allow a full range of movement.

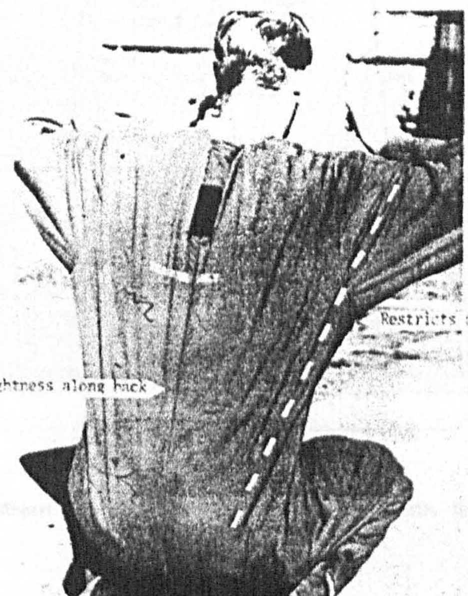


Figure 77 - Restrictive Overgarment. Source: McConville (1986:563)

The stress line on the garment can be seen quite clearly. The fabric is straining and pulling taught. Whilst in this squatting position, the subject is unable to raise his arms above shoulder height. The drop shoulder seam placement, the large sleeve and the dropped armhole, which shortens the underarm seam length, all combine to severely restrict movement.

4.8.1 The Bodice

The crucial areas for fit in the bodice are the shoulder angle, the bust and the armhole. The *conventional bodice pattern is illustrated in* Figure 78. Shoben and Ward (1980) outline the relationship between the garment pattern and the torso.

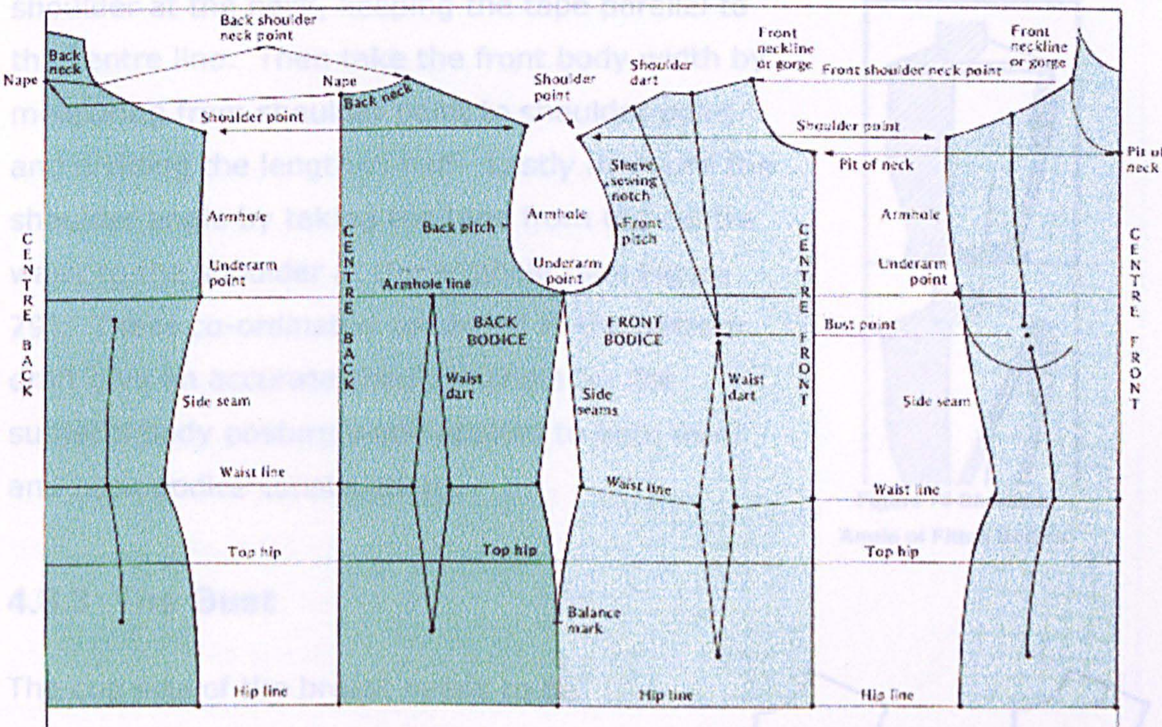


Figure 78 - Conventional Block Pattern Relationship to Body Measurements. Source: Shoben and Ward (1980:39)

4.8.2 The Shoulder Angle

The shoulder angle is crucial to the fit of the garment and is determined by posture and elevation of the shoulders.

Hutchinson (1977) outlines a method for determining the shoulder seam placement using a frame to measure the shoulder angle, however, the technique uses complex equipment that is not readily available.

Rohr (1957:7) explains how to achieve an accurate shoulder angle by taking three simple measurements. Firstly measure the shoulder height, by taking the tape from the waist to the shoulder at the neck, keeping the tape parallel to the centre line. Then take the front body width by measuring from shoulder point to shoulder point and dividing the length in half. Lastly measure the shoulder angle by taking the tape from the centre waist to the shoulder at the armhole (see Figure 79). These co-ordinates combined in the pattern draft give an accurate shoulder angle for the subjects body posture when applied to both front and back bodice constructions.

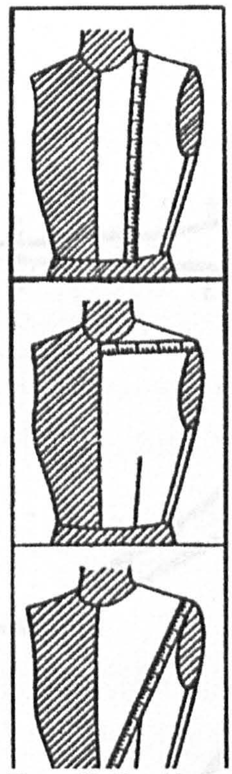


Figure 79 Shoulder Angle of Fitted Bodice

4.8.3 The Bust

The cup size of the breast needs to be accommodated without impinging on the contoured fit of the armhole. The larger cup size often leaves the armhole gaping at the intersection between the arm and chest. This problem for fit can be overcome, as demonstrated by Rohr, (1957:7) by slashing

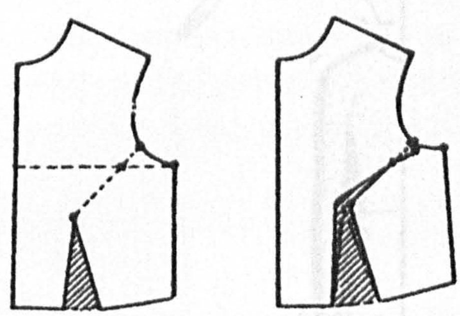


Figure 80 - Pattern Manipulation for the Larger Bust. Source: Rohr (1957:7)

from the armhole to the bust point of the front waist suppression, pivoting the dart to open it slightly and lapping the pattern at the armhole (see Figure 80).

4.8.4 The Sleeve

The range of movement to be performed by the arm is accommodated by altering the sleeve pattern profile. The alignment of the arm to the body determines the shape at the armscye intersection.

4.8.4.1 Kimono

The simplest form of sleeve construction is the Kimono or Magyar sleeve, which is used extensively in babywear, knit garments and outerwear. Bray (1974 16-41) has a comprehensive section in her pattern design book on the theory and production of the kimono block pattern. The simplest kimono pattern drapes to the body form when the arm is abducted to shoulder height (see Figure 81 and has no shoulder angle or shaping. When viewed as a two-dimensional flat pattern it forms the letter 'T'. To improve the cut and fit, making it more like a bodice with set-in sleeves can create a variety of problems. She states that arriving at good results is achieved through understanding and knowing how to deal with the problems as they arise. The top and underarm fabric lengths emboldened on the torso and arm illustrations have a direct bearing on the pattern profile and the range of arm movement. A fundamental fitting problem

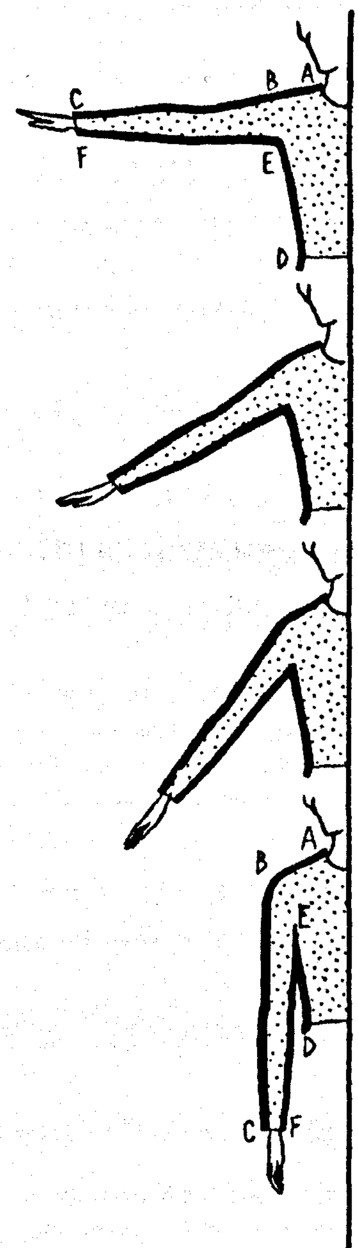


Figure 81 - The Effect of Arm Position on the Length of the Top Arm Line ABC and the Underarm Line DEF. Source: Bray (1978:15)

occurs as a result of the bodice and sleeve being combined, this means the emphasis is on the sleeve angle relationship to the body. There is sufficient underarm length to allow the arm to move freely upwards, creases form as the arm is adducted, straining the fabric, which becomes tight over the upper arm. The sleeve alignment will assume a smooth line over the top arm, but the shorter length under the arm makes it difficult to fully abduct the arm.

One of the ways in which the problem can be overcome is through the insertion of a gusset (see Figure 82), which adds extra length under the arm and allows the arm greater freedom of movement.

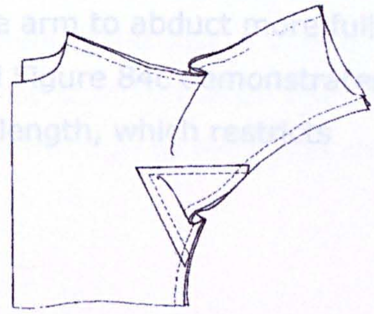


Figure 82 - Kimono Sleeve with Inserted Gusset using *Two Triangular Pieces*. *Source:* Ingham and Covey (1980:115)

4.8.4.2 Set-in

For a conventional set in sleeve, the head height and shape of the sleeve reflects the shape of an arm hanging in a relaxed position by the side of the body (see Figure 83). The sleeve torso angle relationship affects the degree of freedom of arm movement. The pattern adjustment that lowers the armhole, maintaining the crown height and shape in the sleeve, reduces the

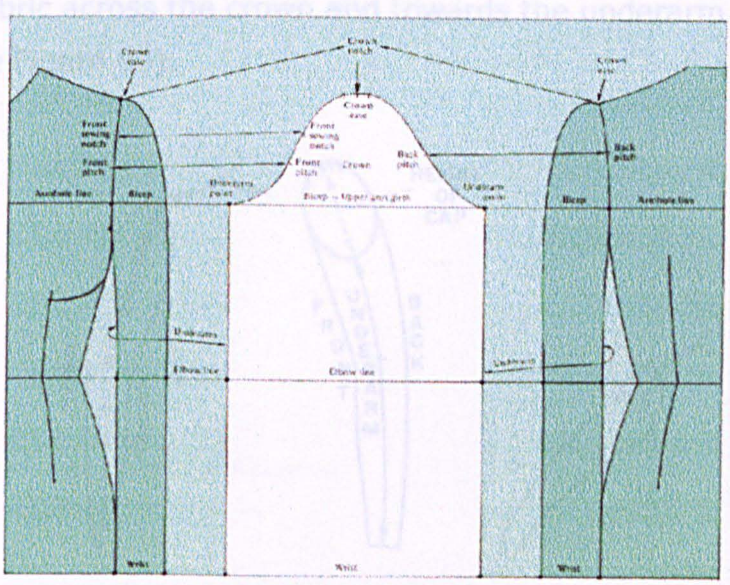


Figure 83 - Conventional Set in Sleeve Pattern Relationship. Source: Shoben and Ward (1980:40)

under arm seam, this ties the arm closely to the body. Watkins (1995:253) maintains that: *"A seam that comes up high into the armpit and returns down the full length of the arm provides the greatest underarm seam length and allows the arm to abduct more fully."* Although in theory a conventional 'set in' sleeve, of the type illustrated by Watkins in Figure 84a, conforms to the body under the arm and down the length of the underarm seam, this does not necessarily provide for the arm to abduct more fully. Figure 84b shows the lengthened armhole and Figure 84c demonstrates the resulting shorter bodice and underarm sleeve length, which restricts movement.

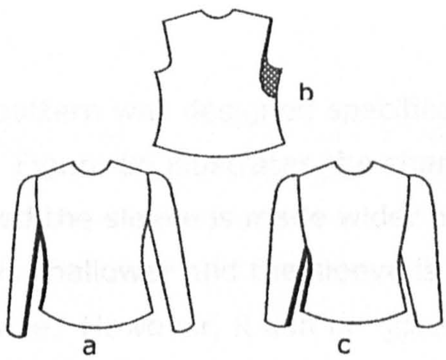


Figure 84- Underarm Line. Source: Watkins (1995:253)

The construction of the crown, in combination with the convergence of the four seams under the arm, can restrict abduction of the arm. This is due to insufficient fabric across the crown and towards the underarm seam junction, (see Figure 85).

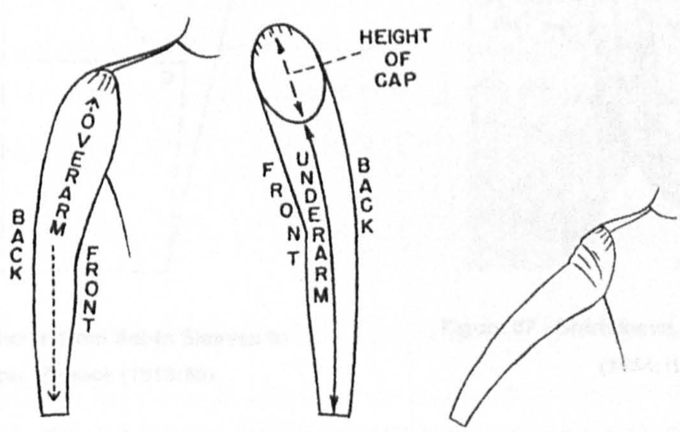


Figure 85 - Relationship of Conventional Sleeve Pattern to the Arm. Source: Pivnick (1958:58)

The resultant pattern profile is thus restrictive where the width and the depth of the head and the derived shape under the arm prevents a wide range of movement. The sleeve fit is at its best when the arm is fully adducted and the crown conforms smoothly around the top of the arm. It is shown in Figure 82 how the arm contour and position relates to the conventional sleeve pattern. The arm can only be abducted approximately half way between waist and shoulder without pulling the rest of the garment out of alignment. As a consequence of the fabric straining when the arm is raised, wrinkles form across the top of the arm through to the underarm restricting movement.

4.8.4.3 Shirt

The conventional shirt pattern was designed specifically to allow the wearer freedom of movement. Figure 86 illustrates the change in pattern profile as the head is foreshortened the sleeve is made wider and the underarm is lengthened. The head is shallower and the sleeve is wider which allows the arm to be raised with ease. However, it can be observed when the arm is lowered, diagonal wrinkles form towards the under arm (see Figure 87).

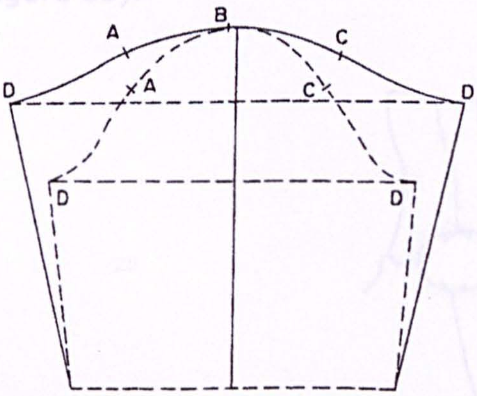


Figure 86 - Pattern Manipulation from Set-in Sleeves to Shirt Sleeve. Source: Pivnick (1958:58)

Figure 87 - Shirtsleeve. Source: Ladbury (1984:107)

4.8.4.4 Gusset

The insertion of a gusset in a conventional set-in sleeve is another method used to enable greater freedom of arm movement and still maintain a close fitting shoulder and crown silhouette. A diamond shaped gusset can be inserted to release the sleeve and side seam at the junction under the arm illustrated in Figure 88 (Ingham and Covey 1980).

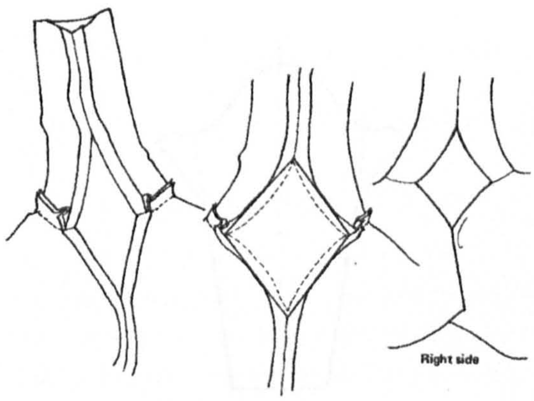


Figure 88 - Diamond-Shaped Gusset. Source: Ingham and Covey (1980:115)

4.8.4.5 Dancers Gusset

The addition of a circular or oval gusset allows extensive arm movements, even in a tightly fitted sleeve and is referred to as a dancer's gusset (see Figure 89).

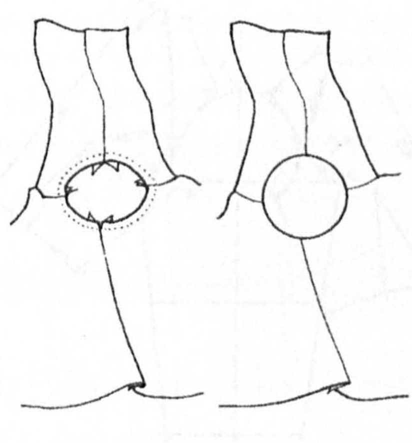


Figure 89 - Dancers' Circular Gusset, Viewed from the Outside of the Garment. Source: Ingham and Covey (1980:116)

The size of the gusset pattern is determined when the arm is raised and the arm pit area is traced. The resultant pattern shape is then inserted at the seam junction under the arm. As the arm is abducted the circular or oval gusset will conform to the armpit and, when the arm is adducted, the gusset forms a small pocket under the arm, but with the sleeve still retaining the tight fitting silhouette of the set-in sleeve. A circular or oval gusset can be constructed as an integral part of the pattern draft for a one-piece sleeve, illustrated in Figure 90.

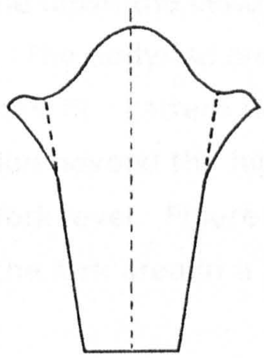


Figure 90 - Gusset as an Integral Part of the Sleeve Pattern. Ingham and Covey (1980:116)

4.8.4.6 Raglan sleeve

The raglan sleeve is formed when the crown is incorporated with the shoulder area of the bodice as illustrated in Figure 91. In combining the

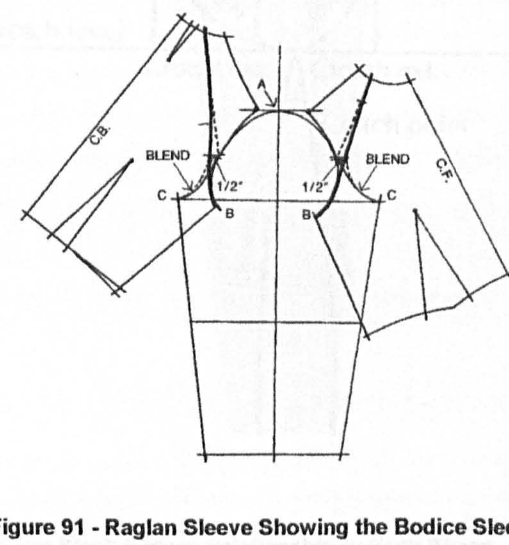


Figure 91 - Raglan Sleeve Showing the Bodice Sleeve Distribution. Source: Armstrong (1995:344)

bodice and sleeve the pattern can then be manipulated to fit obtaining results similar to the set-in sleeve. The raglan can also be cut from the kimono block which, with the addition of a diagonal seam between the bodice and sleeve, makes changing the pattern profile under the arm and the insertion of gussets significantly easier.

4.8.5 Bifurcated Garments

To produce a bifurcated garment, traditionally the woven block pattern was constructed to allow a crease line down the centre front and back of the leg, corresponding to the grain line. The bodyrise and seat angle and the overall fork length determine the garment fit. Pattern drafting systems in general apportion the fork point extension beyond the hip by a mathematical formula to define the shape at fork level. Figure 92 illustrates the way a pattern is expected to contour the fork area in a bifurcated garment.

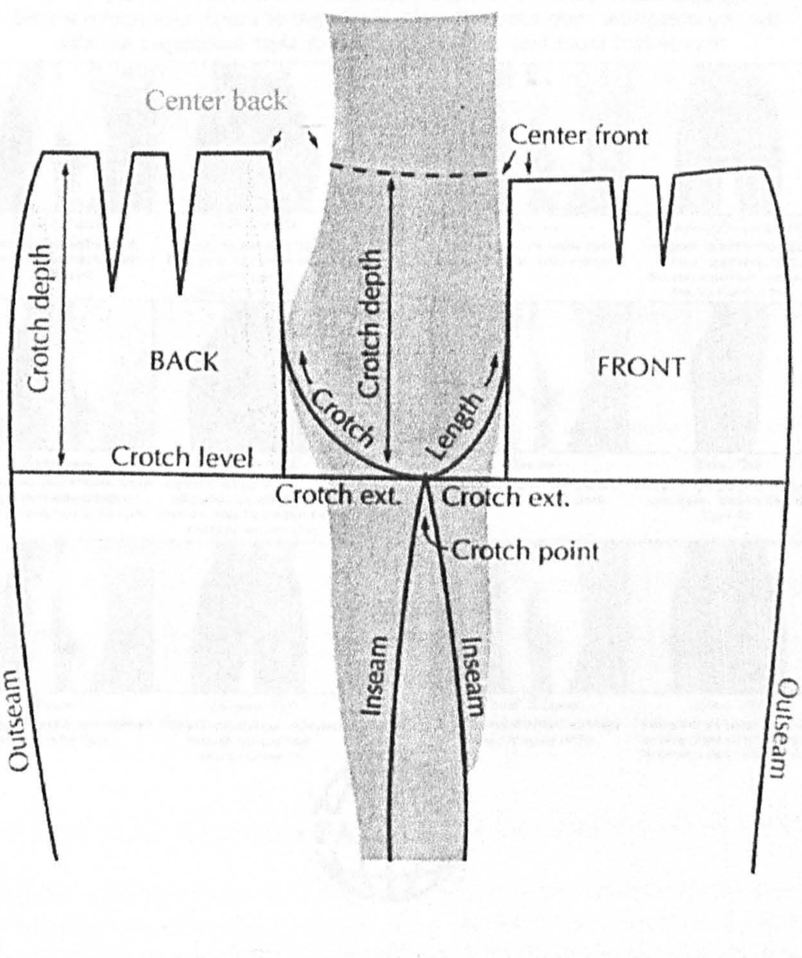


Figure 92 – Conventional Trouser Block Pattern Relationship to Body Shape. Source: Armstrong (1987:531)

4.8.5.1 Trousers

Body shape (see Figure 93) has major implications for the fit quality to accommodate the individual. The body contour shape of the abdomen and seat determines the curve of body rise and seat angle. The torso contour seat depth and width relationship cannot be determined by the body rise and crutch length measurements required to derive the pattern geometry of the seat angle in a conventional jeans pattern. Although the jeans advert acknowledges the need for different cuts to flatter divergent shapes. Whether or not a good fit has been achieved is open to interpretation, but arguably the fit could be improved.

Figure 93 - Falmer Jean Advertisement. Source: Vogue (1995)

Available methods for calculating the amount to add onto the hip measurement, to determine the placement of the fork point in trouser block construction for both woven and stretch blocks, are difficult to apply successfully. The seams converge from two different planes and the hollowing out process affects the fit (see Figure 94). Changing the body rise, seat angle and the openness of the legs are all contributory factors in allowing freedom for flexion or abduction of the legs (see Figure 95).

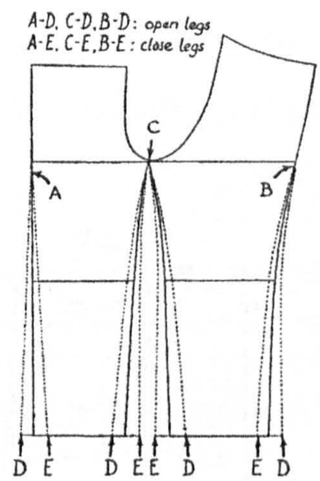


Figure 94 - Conventional Trouser Block Pattern Seat Angle Placement. Source: King Wilson (1948:24)

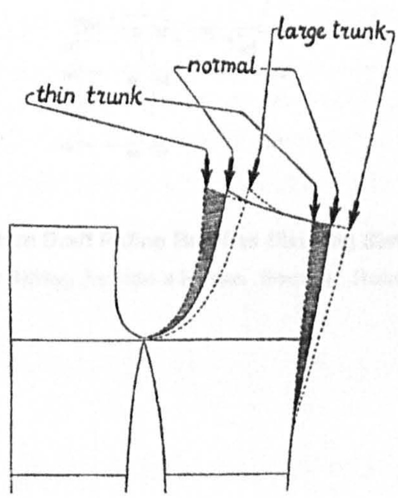


Figure 95 - Conventional Trouser Block Pattern Leg Alignment. Source: King Wilson (1948:24)

4.8.5.2 Riding Breeches

The draft for riding breeches shown in Figure 96 illustrates how a person can sit comfortably astride a horse with the knees bent. The seat angle at the back is increased and the front body rise is shortened to reduce fabric buckling which occurs when seated. The increased width across the seat at the fork point accommodates the seated body expansion across the buttocks. The legs are abducted to allow for an easy open leg posture and gore at the back of the knee replaces the folds that occur when the knee is bent.

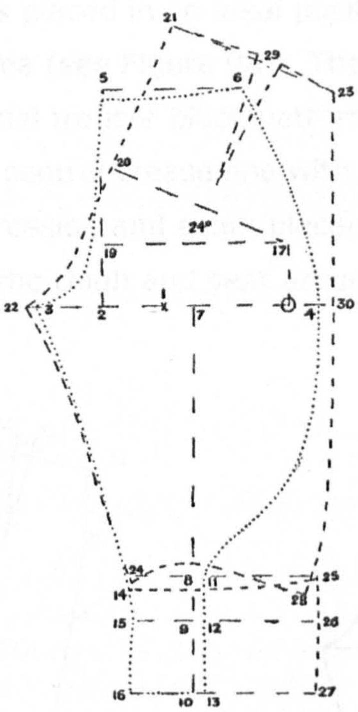


Figure 96 - Conventional Pattern Draft Riding Britches Showing Slat Angle and Open Leg Position Suitable for Sitting Astride a Horse. Source: Hulme (1946:129)

4.8.5.3 Crutch Gusset

A gusset can be inserted in the fork area (see Figure 97) to provide for greater separate leg mobility, Watkins (1995).

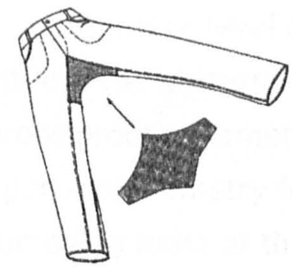


Figure 97- Crutch Gusset. Source: Watkins (1995:247)

4.8.5.4 Contour

The discussion on bifurcated grading by Taylor and Shoben, (1990) outlines a grade plan of a body measurement contour bifurcated garment, with seams and suppressions placed in an ideal position to give maximum movement of the hip area (see Figure 98). The pattern profile shape is different to a conventional trouser block pattern (see Figure 99), which has a front and back with a central crease line with the leg and torso combined in one piece. The suppression and seam placement controls the shape to contour closely around the thigh and seat around the fork.

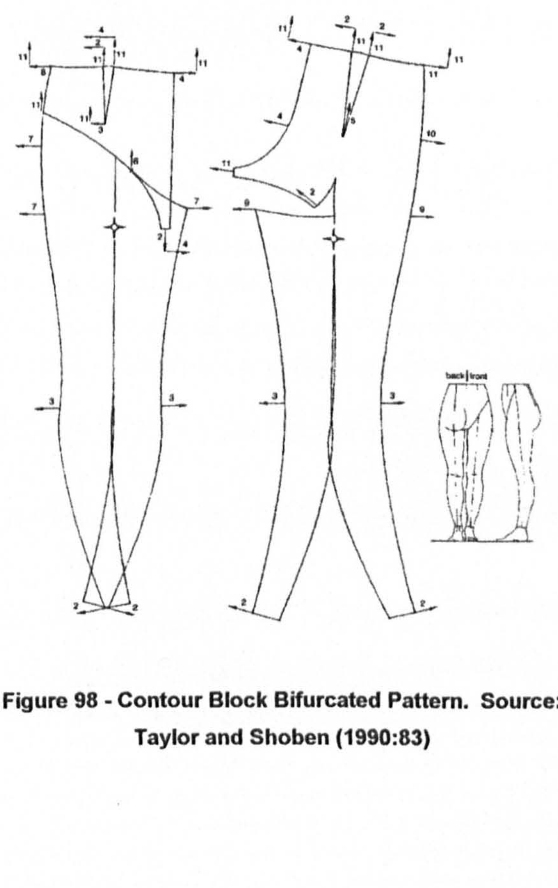


Figure 98 - Contour Block Bifurcated Pattern. Source: Taylor and Shoben (1990:83)

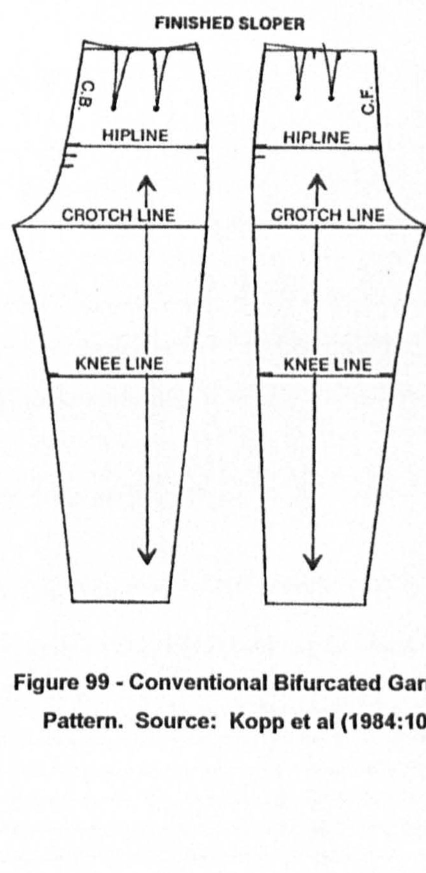


Figure 99 - Conventional Bifurcated Garment Pattern. Source: Kopp et al (1984:105)

There are differences in the pattern geometry between the two figures. If the suppression of the waist, hip, thigh and around the fork level could be combined in the flat, two-dimensional plane, without the pattern buckling, then the pattern piece would have quite a different profile geometry to that of the traditional pattern profile. However the pattern geometry for stretch fabrics are usually simplified and rationalised removing most of the curves in the belief that the stretch fabric will adjust to adequately fit the undulating body contour.

4.9 SUMMARY OF FIT FOR MOVEMENT

Preparatory study in the areas of the anatomy where localised movement has an impact on a basic block pattern is an essential step in stretch block pattern development.

Comprehensive movement notation is an invaluable tool and Deng (1996: 24-47) outlined an upper body posture coding system taking a basic stick drawing with the joint location between body segments defined. This allowed a range of movements to be conveyed in simple format, which could be developed as a notation aid for the performancewear designer.

The adoption of an appropriate systematic observational strategy for information processing is vital; the flexibility of the approach strategy should be based on the purpose of the analysis. Good preparation is vital in obtaining accurate information as the observer has information that crosses many disciplines. In order to identify movements that are critical to a specific sports garment, it is essential for the observer to familiarise him or herself with the particular pattern of activity. The observer is then better able to evaluate movement in terms of position and frequency, since even the smallest movement at a high frequency rate can become critical for the design specification.

A remedy for poor fit cannot be identified without understanding the theory behind the pattern design in relation to the active three-dimensional body shape and posture. A quality garment-to-body fit relationship is dependent on the pattern profile conforming to the body profile. In designing for movement there may be certain ways in which the garment pattern is altered to promote ease of movement which will look good in the posture that they are intended to facilitate. However, the garment may not be aesthetically pleasing when in an upright or relaxed position prior to assuming the sports posture.

Ibrahim in section 4.6.4 suggested that a comparison between the free body average strain (17%), and the free-body maximum local expansion

(35%), might be a more useful prediction of maximum fabric strain during bending. The conclusion reached was that the degree of stretch utilised in movement would not exceed the available fabric stretch and therefore should not impinge on the garment design. However, if there are inconsistencies in the garment-to-body fit relationship and the movement is excessive, or the fabric is consistently over stressed this may cause discomfort and restrict the movement of the wearer. In these circumstances the garment fit may be inappropriate therefore, the vulnerable areas should be analysed and adjustments made to the pattern profile geometry accordingly.

The orientation of the pattern piece on the fabric affects the garment fit in wear. The higher power, or direction of least stretch, is aligned horizontally around the body reducing garment slippage during bending. The lower power, or direction of most stretch, is aligned in the vertical direction increasing the capacity for extension in the direction of maximum elongation of the body. This orientation counteracts the garment riding up or pulling down.

The area commentaries highlight some of the ways in which patterns are developed to promote movement. Conventional block patterns constructed for non-stretch woven fabrics are manipulated and enlarged using a variety of techniques to facilitate movement. This can be achieved by proportionally enlarging the garment or by the addition of fabric to the length or width in strategic places, or by incorporating gathers, pleats, tucks, panels or gussets. The principals and the rationale for implementing these pattern construction techniques to facilitate movement is of great value in the development of the stretch block pattern to accommodate either a defined body posture or a specific movement range.

CHAPTER FIVE

5 STRETCH BLOCK PATTERN DEVELOPMENT

5.1 STRETCH BLOCK PATTERN INTRODUCTION

Pattern drafting techniques for woven block patterns are well established. Applying existing techniques to generate patterns for relatively new stretch fabrics can be successful, but it is often at a cost. It does not necessarily hold true that to pattern design for stretch fabric, using the simplified shapes of modified conventional patterns, will automatically give an acceptable contour fit. Those who are familiar with current stretch garments will be aware that many constantly have to be readjusted after movement to feel comfortable!

The consensus appears to be that modification of a block pattern for woven fabric is the logical starting point for developing a block pattern for stretch fabric. However, it has been ascertained that the reduced pattern profile geometry of a modified conventional block patterns which has been rationalised by approximating the pattern profile into straighter lines and more fluid curves is not always appropriate for a body contouring stretch garment. It was the reinterpretation of the underlying principals of conventional patterns and the overall understanding of the relationship between the dynamic body form, the flat pattern and the fabric stretch characteristics that has impelled the development of the new stretch block pattern, which was constructed by applying direct body measurements.

The whole complex process of design development follows the model outlined in Chapter One, where the design situation has been explored and many problem areas have been perceived, assessed and interpreted in a cyclical process. A successful stretch block pattern profile is achievable through understanding the interrelationship between the stretch fabric behaviour, the dynamic body contour and the two-dimensional pattern. The perceived fit quality impels the interpretation of these factors in the rationale for replicating the dynamic body contour in the new stretch block pattern.

5.2 STRETCH BLOCK PATTERN METHODOLOGY

The stretch block pattern analysis garments were constructed in a warp knit stretch fabric Coolmax®, a performance fabric manufactured by Penn Nylar. The fabric composition details are outlined in Table 7 (a copy of Table 3 in section 2.7.1.2).

Code	Quality	Description	Polyester %	Elastane %	Colour
A	21649	32gg 210g Coolmax/Lycra	84	16	White NR5079
B	21132	32gg 260g Animalmax	88	12	White SDI 10014
C	21132	32gg 260g Animalmax	88	12	White NR4888
D	22203	56gg 220g Coomax/T902 Triskin	80	20	White SDI 10515
E	21130	32gg 180g Coolmax/Lycra	84	16	White SDI 15243

Table 7 – Fabric Sample Characteristics

The contour fit categories used in this study were confined to the form fit and action fit level as outlined in section 5.4.1. As the body contouring stretch block pattern is intended primarily as a template for design development, only aesthetic considerations directly associated with fit have been included.

A Kennett and Lindsell Full Length dress stand, Size 12 referred to as Dolly was used in the stretch block pattern development process. Although dolly's size is referred to, the concept of using measurements from standard size charts other than as a general indication, is not otherwise relevant in this study.

It is the body shape and posture that is the key in the pattern construction method and the pattern profile geometry is defined by direct body measurements. A measurement specification key and chart in sections 5.5.5 and 5.5.6 details the body landmarks and the measurement technique employed.

An overall body measurement map was obtained by taking a comprehensive number of measurements, although a reduction in the number of measurements may be of benefit when employing manual measurement techniques and, time permitting, could possibly be achieved without detriment to the pattern profile. However, with advances in accurate rapid body scanning techniques and computer technology to interpret the data dynamically then the number of measurements may be of minor consideration in the pursuit of customised fit.

The measurements specified in stretch block drafting rules section 5.8 are those of Dolly. The pattern draft method sectionalised the body, which was then plotted in detail using direct body reference points to determine the form fit pattern profile shape. The first division was made between centre front and centre back and at the apex of the shoulder, then at each side, including the division along the shoulder. The side seam placement is not taken as a literal plumb line perpendicular to the floor but is an aesthetic division, creating a visual balance between the front and back sections. The body was then systematically defined on the horizontal plane and delineated. Using a system inspired by the Somatotyping classification system (Sheldon et al 1940), horizontal measurements of body diameters located at the levels where contours change were taken with an anthropometer. A tape was then used to take circumferences and diagonal measurements between allocated points.

Traditional pattern drafting methods are time consuming, consequently in this study the pattern production process was computerised. A spreadsheet was used to store all of the measurements and the drafting rules. The integrated process allowed the final designs for all pattern pieces to be printed onto paper, which speeded up the whole process considerably.

The basic stretch block pattern profile contours the body in a form fit. The form fit stretch block pattern was then reduced. The amount by which the form fit stretch block pattern was reduced used only some of the available fabric stretch. The specific amount was based on a new interpretation of a hanger load test method to quantify the degree of extension in a stretch fabric. The quad load test method (section 2.8) established the degree of stretch extension through applying a force to the length of a given sample. Each sample set included fabric cut in the course, wale and two bias directions.

The proportion of the calculated stretch extension measurement and the way it was to be applied to the form fit stretch block pattern was determined through interpreting the effect of the stretch characteristics related to the 2D pattern geometry, when subsequently stretched to conform to the three-dimensional body. This was achieved by reducing the fabric pattern dimensions horizontally and vertically, by different amounts related to the force exerted on the body by the proximity of the garment to the body (the fit level category) and the modulus of the stretch fabric.

The stretch reduction factor RF is expressed as an individual unit value and is derived using the following equation where SE represents the degree of stretch extension. The stretch extension is a function of the fabric stretch characteristics, the axis ratio and the level of fit. The reduction factor is referred to in detail in Section 5.6.2.

$$\text{Reduction Factor } RF = \frac{100}{100 + SE}$$

An example of the degree of stretch and corresponding stretch reduction factor is shown (to 2 d.p.) in Table 8.

Stretch extension **SE%**	5	10	15	20	25	30
Reduction factor **RF**	.95	.91	.87	.83	.80	.78

Table 8 – Stretch Reduction Factor

The application of a uniform horizontal and vertical reduction to the form fit stretch block pattern was deemed appropriate for the type of fit requirement over the body measurement range for the test garments. The difference in the pattern profile geometry taken from direct body measurements and the amount of available stretch to be used meant that the tension brought about by the small radii at the wrists and ankles was not great enough to cause any discomfort or over stress the fabric.

The shape of the fabric will affect the way the stretch characteristics deform. A visual appreciation of the overall knit stretch fabric distortion characteristics as highlighted in section 2.5 was essential to the process of pattern production through garment fit analysis and evaluation. The transposition and interpretation of the stretch characteristics of various shapes, such as rectangles, trapezoids and triangles was applied subjectively to maximise the stretch garment fit potential. The garment fit quality was enhanced by application of this technique through, for example, adopting a bodice to sleeve angle relationship approximating to a subject standing with the arms abducted at 45°.

To identify and visually asses the effects of fabric stretch characteristics the fabric for the toile was marked with 2.5cm squares, which illustrated local curvilinear distortion by highlighting the direction of stretch relative to the pattern straight grain line and the amount of stretch distortion at each square

The pattern design development was highly complex requiring the interrelated factors to be prioritised and channelled through the process of analysis, evaluation and application which is cyclical and is repeated at each level until an acceptable outcome is reached.

A fitting scheme was implemented to maintain a systematic approach to analysis and evaluation in the design development process. The fitting scheme was also used as a basis for the chart used to focus the analysis and evaluation of photographs taken of the bodysuits.

To maintain continuity and to eliminate as many variables as possible Dolly (dress stand) was used to assess the overall appearance of the toile in the initial developmental stages of producing the stretch block pattern. However, it was not possible to assess the toile in the defined posture or for mobility and comfort, as Dolly was inflexible!

It is desirable that the stretch block pattern profile will smoothly contour the body, be comfortable and accommodate a gamut of movement without straining or displacement of the fabric. However, it is impossible to design a contoured garment that remains completely smooth whatever the movement; even human skin cannot achieve this!

A realistic assessment of the stretch block pattern could only be achieved when the garment was worn by a human subject and then only when it was warm after a series of movements (which fully flexed the fabric; highlighting any fabric to body fit disparities), had been completed. The fit potential was then analysed and evaluated on cessation of movement when the subject stood in a specific posture; a normal upright stance, with the exception that the arms were positioned at 45° with hands placed on the hips.

For the assessment of fit, mobility and comfort, three representative somato shapes were chosen to test fit the bodysuits; Michael, Fiona and Natasha. A video 'Action Fit in Motion' features Fiona wearing garments B and E. The choreography was designed to subject the garments to an extensive range of movements and demonstrate the dynamics of fabric stretch and recovery of the stretch block pattern action fit level category. The movement range is an amalgam of those described in Section 4.3, including circumduction of the limbs and deep body bends, which fully mobilised the body encompassing the basic movements required by a wide range of sporting activities.

5.3 STRETCH PATTERN IDEATION

Producing a form fit flat pattern, without darts, that closely adheres to the contours of the body without restricting movement, is a contradiction in design terms. In woven fabric, darts and ease are used to manipulate the fabric around the form and allow movement. In a knit stretch garment without darts to contour the body, a degree of stretch distortion in areas of protrusion is inevitable. A contoured form fit pattern should produce a garment that has no wrinkles, minimal stretch distortion and conforms to the body, rather like a second skin.

> The way in which a problem is defined has direct consequences for the boundaries of the designers work and the creativity with which the problem could be solved (Watkins 1998: 12)

Juggling in one's 'minds eye' the interrelationship of the stretch characteristics of the fabric, in conjunction with an understanding of the 3D sculptural form of the body, the type of movements required and how these factors determine the flat pattern profile is necessary when observing and evaluating the fit quality of the stretch block pattern analysis toile.

The toile has no darts or inserts to accommodate the body curves and hollows it is the gridlines marked on the analysis toile that allow the designer to visualise stretch deformation over the body contours.

Gridlines not only enable the observer to identify areas of unacceptable stretch, which is indicative of the pattern profile being incorrect, but also they confirm that the horizontal and vertical toile/body placement aligns as the designer intended.

Using a grid system is essential, especially in the developmental stages of producing a stretch block pattern. It is in evaluating the fit stretch characteristics of the toile in its 3D form that builds a vision of how the flat pattern should look. However, to gain this experience one first has to construct the pattern profile for a specified fit to accommodate the body shape, posture and envisaged movements and then determine the proportion of the available stretch to be called upon, before making up the toile so, creating the initial pattern profile is almost a leap of faith.

The individual's subjective assessment of comfort and fit is an important factor when trying to gage the feel of the garment when donned and the impression gained during and after experiencing movement. Frictional resistance can influence the garment fit which may be brought about by moisture on the skin or in areas where there is an additional layer of fabric between the skin and the bodysuit. The quality of the stretch fit can also be affected by tie or anchor points, which are located at garment restraint points and at torso limb junctions like the armpits and the crutch.

Conventional patterns are derived from girth circumferences and the body is divided equally, front and back and the pattern geometry is rationalised; approximated into straight lines and fluid curves. This causes a series of calculation and distribution problems in the geometry of a modified conventional pattern profile for stretch fabric. By sectionalising the body into quarters, using both the centre line and side seam as reference points and taking both anthropometric width and girth measurements, it is possible to create a pattern profile based on direct physical measurements and not derived measurements. This approach, although time consuming if a completely manual approach is adopted, significantly reduces the margin for error in body profiling and, therefore, has the potential to vastly improve fit which must be beneficial.

5.3.1 Stretch Extension

Stretch pattern development depends on contextural knowledge. Available information on obtaining and applying the degree of stretch extension is inadequate; the designer needs to know *how* to quantify stretch extension consistently and easily. Fabric stretch quantification is the first step in the procedure to establish the amount by which the pattern is reduced to accommodate the proportion of the available fabric stretch to be used, which is consistent with providing a fit quality appropriate to the fit requirement. Therefore the requirements are a *method* and the *rationale,* which are *inextricably linked.*

The degree of stretch extension is established through applying a force to the relaxed length of a given sample. Fabric that stretches in one direction only is usually referred to as uni-directional stretch fabric. The course and wale direction of fabric stretch can differ and is usually referred to as a bi-directional stretch. However, in bi-directional fabric the stretch is always *multi*-directional, although they may have the same degree of stretch in the course and wale, the bias stretch is always different. Therefore, quantifying the degree of bias stretch is important. It is this aspect of the fabric stretch curvilinear distortion characteristic which cannot be ignored because the bias stretch has a significant influence on the pattern profile geometry as the fabric contours the undulating body profile. The stretch distortion characteristics can inhibit or enhance the fit of the pattern profile or the aesthetics of the final design.

There is little information on where and by how much to reduce the block pattern profile geometry in order to stretch and contour the body comfortably without fabric displacement. The application of a uniform stretch reduction factor is not always appropriate. Assuming that the degree of stretch is maintained at a constant rate, as the curved surface of the body mass decreases, the pressure on the body exerted by the fabric will increase. This can considerably reduce the fabric diameter below the elbows and knees, and therefore the limited available stretch can affect comfort. The effect of radius of curvature may necessitate adjustment of the pattern profile, particularly towards the extremities although the adoption of a pattern profile based on direct body measurements should facilitate a dynamic approach to pattern adjustment for radius of curvature.

5.3.2 Pattern Reduction

The stretch reduction factor applied to the garment pattern is determined by a combination of the stretch extension and the required fit. The garment fit is related to the force exerted on the body by the proximity of the garment to the body and the modulus or hugging power of the stretch fabric.

The stretch reduction factor applied to a garment is a function of fit. Examples would be a form fit garment that contours the body without stretching which would apply zero pressure, an action (stretch) fit would apply some pressure and power (compression) fit would exert a proportionally higher pressure and significantly alter the contours of the body (see Contour Fit Description Section 5.4.1). The fit level is achieved by reducing the fabric pattern dimensions by different amounts.

5.3.3 Pattern Geometry and Stretch Characteristics

When constructing garments from woven or dimensionally stable knit fabrics, a degree of ease is built in during the first stages of the pattern design to overcome constriction in localised areas. However, for a stretch knit fabric the tendency might be to reduce the pattern without changing the pattern geometry, with the assumption that it will automatically stretch in the right places to give an acceptable fit. Understanding the behaviour of fabric stretch distortion characteristics is crucial to predicting the garment pattern profile geometry. The application of gridlines to the analysis garment highlighted the effect of stretch distortion characteristics. This visual technique clarified the need to move away from a conventional approach to constructing a stretch block pattern and to move towards developing a method of applying direct body measurements.

The pattern should be perceived as being constructed from an array of geometrical shapes and any areas of the pattern that are not predominantly rectangular need to be defined in terms of the predominant geometrical shape. With these considerations in mind it is possible to apply what has been observed by looking at visual linear stretch distortion and force/extension characteristics, of both straight and triangular pieces of fabric. The linear and non-linear stretch characteristics for the fabric can be transposed to predict the geometry of the pattern profile.

Patterns are, by nature, irregular and contain areas where there will be a non-linear relationship between relaxed length and the required stretch. The critical areas are the shoulders, the bust, under the arm, the seat angle, the bodyrise, the fork point and the thigh, which need to be reassessed for potential geometrical stretch behaviour.

If a garment pattern is interpreted as an array of geometric shapes the sleeve would be predominantly rectangular and the crown might be considered to be trapezoidal, with the under arm and crutch areas more like triangles. The shape of the fabric will affect the way in which it deforms because as the apex of a triangle is approached, the fabric will stretch further.

An example is the crown where the predominant geometrical shape would be a trapezoid (a truncated triangle). The apex of the crown is vulnerable to the greatest deformity as the shape of the fabric effects the way in which it deforms. As tension is applied to a triangular shape, it will deform in relation to the forces and this brings about a non-linear stretch characteristic towards the apex of the triangle. Therefore, the construction of the crown would be shallow to allow for the effects of stretch characteristics of the predominant geometrical shape.

5.3.4 Area Commentaries

The relationship between the high points of the body contours, bust, upper and lower hip, bottom and waist, knees and ankles will dictate the shape of the contour of the pattern profile. The disparity between the measurements of the pattern profile curves may be too pronounced for the fabric to fit smoothly over the contours of the body without buckling. Therefore, where the seams converge, the pattern may need to be adjusted in order to harmonise with the body. Curves might need to be modified slightly but a small amount can usually be accommodated within the fabric stretch parameters.

5.3.4.1 The Bodice

In most stretch patterns it is recommended that the front and the back bodice and the front and the back sleeve are same profile shape, with the exception of the neckline and occasionally the front armhole, which are slightly hollowed out. The centre of the crown is usually aligned with the shoulder seam and an equal amount of sleeve fabric is distributed at each side. However, this is not always appropriate as different body shape types and postures (see Figure 100) may require a crown pattern profile with an unequal distribution.

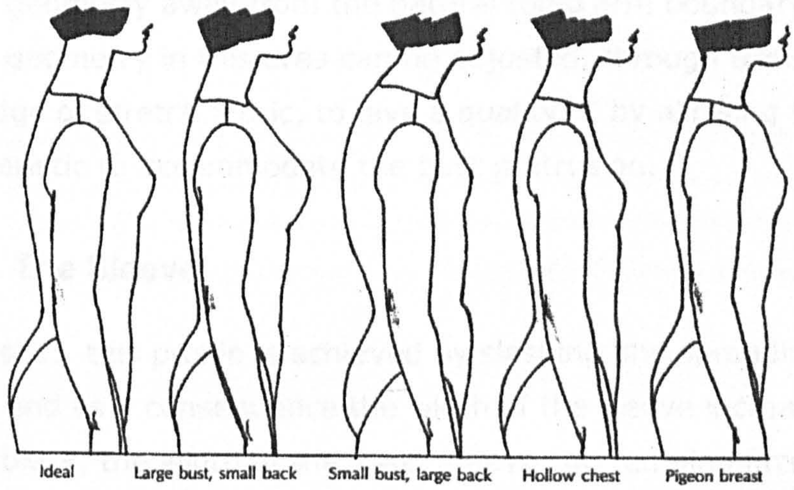


Figure 100 – Different Body Shapes and Posture. Source: Armstrong (1995:38)

5.3.4.2 The Shoulder

The pattern profile at the shoulder is dependent on the angle and posture of the body as illustrated in Figure 100. The shoulder height can be established by taking the measurement from the neck at the shoulder line parallel with the centre front line to the waist. The measurement that determines the shoulder angle is taken from the shoulder point at the end of the shoulder line at the armscye, either to the centre front at the waistline or the centre back at the waistline (see Figure 79 in section 4.8.2). The placement of the shoulder seam affects the distribution of the armscye measurement between the front and back armhole on the bodice and this determines the crown measurement distribution.

5.3.4.3 The Bust

Usually a standard size twelve sample block pattern is for an average 'B' cup size. However, the size and position of the bust can vary considerably depending on age and type of support, if any. Conventionally the bust girth is divided equally between front and back pattern pieces including ease. The implications of this for a stretch pattern are the larger the bust the greater the disparity between the body profile and the pattern profile in the width and the depth front to back under the arm. In a stretch fabric the relative girth size and fullness of the bust adversely affect the underarm and front armhole of the pattern profile shape which diverts the armscye pattern geometry away from the natural torso arm boundary line. The pattern geometry in this area can be adjusted, through transposing knowledge of stretch fabric, to give a quality fit by allowing the bias stretch characteristic to accommodate the bust protrusion.

5.3.4.4 The Sleeve

On the shirt, this profile is achieved by slashing and spreading the sleeve pattern and as a consequence the width of the sleeve increases. In the stretch block, the width of the lower sleeve can remain narrow, yet still increase in width between the underarm seam junctions, this reduces the crown depth, allowing the arm to move freely as the fabric stretches. Thus a smooth silhouette is retained at the underarm and shoulder during and after movement. The depth of the crown can be calculated from the shoulder point at the top of the crown to the intersection between the arm and chest (see Figure 101). This depth becomes shallower as the geometry of the pattern profile changes to allow for the effect of the fabric geometry and the stretch characteristics for a specific posture and the movements envisaged. The bodice sleeve angle relationship in the stretch block pattern approximates to a subject standing with the arms abducted at 45°. The stretch characteristics of the fabric can be utilised to accommodate a range of movements without fabric displacement by adopting the shallower crown shape of the shirt.

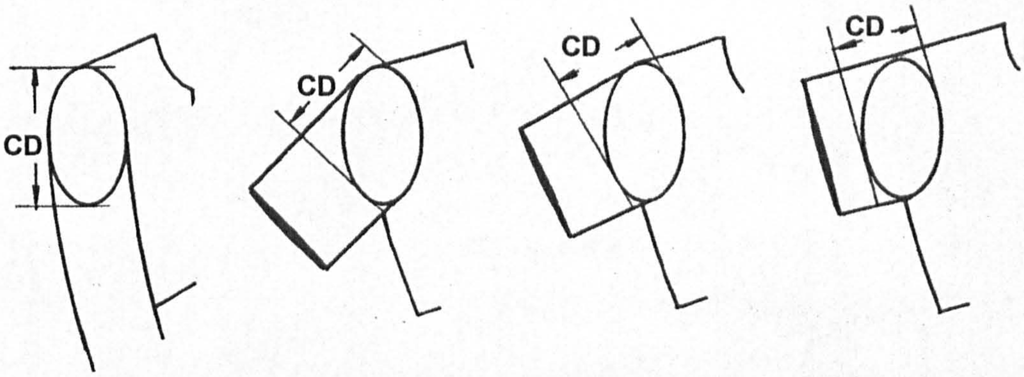


Figure 101 - Crown Depth. Source: Adapted from Shoben and Ward (1987:21)

5.3.4.5 The Bifurcated Garments

It is well recognised that the area around the crutch is particularly difficult to fit well and the process of applying traditional pattern construction techniques to stretch garments compounds the problems. Although stretch should 'make the fit better' the results of poor fit quality around the crutch and an inaccurate leg alignment can be readily discerned, as many stretch garments have to be readjusted to the body to feel comfortable.

The pattern profile in conjunction with the stretch fabric geometry determines the quality of the stretch garment fit if, for example, the overall fork level is to short and the geometry towards the intersection at the fork point is inappropriate, this will allow the fabric to retract between the buttocks. However, if the fabric is not anchored at the waist, then the fabric can ride down the leg and assume a position hanging below the fork level, as it strains to retract during movement. Any long-term fabric distortion places extra strain on the elastane fibre causing fabric fatigue.

The stretch pattern, when released from traditional constraints but with the fundamental principal retained and combined with a new method of measuring the fork point extension, produces a different pattern profile geometry. This profile contours closely the sections of the torso and the legs as they converge to meet the fork point. This measurement is taken through the leg to allow for the differences between the top of the thigh and the torso.

5.4 FIT ANALYSIS AND EVALUATION

There are a number of textbooks that address the problem of fitting and pattern alteration for woven garments Liechty et al (1986) Bray (1978) Armstrong (1995) Rasband (1995). Texts on fit and pattern alteration for stretch garments or the interaction of stretch characteristics with fit are rarely, if ever, included. However, wrinkle analysis is a widely used and documented method that is appropriate for analysis and evaluation of stretch garments. Wrinkles indicate the strain or looseness of the garment, neither of which is desirable.

It is difficult to apply the standard fitting techniques of slashing, lapping or inserting fabric in order to modify a stretch garment. If the pivot method is used indiscriminately to manipulate the fit then the pattern profile can become distorted. The seam method does not alter the basic shape of the pattern profile so its use is limited. The most successful means of altering the fit of a stretch garment with minimum distortion is through manipulating the pattern profile geometry to the desired shape at the flat pattern construction stage.

It is imperative that the new stretch block conforms closely to the body contours in an accurate form fit. Understanding the methods outlined by Liechty, Pottberg and Rasband (1986) in Fitting and Pattern Alteration: A Multi-Method Approach to correcting the pattern profile shape demonstrates that having a clear picture of the fit problem is the first step to identifying the appropriate solution.

The quality of the body contouring stretch garment fit is inextricably linked to the fabric stretch potential and the garment analysis was achieved through the process of:

- Identifying the proximity of the garment-to-body fit relationship.
- Identifying the body posture encompassing mobility to be accommodated.

- Identifying the factors that promote a quality garment-to-body fit relationship.
- Identifying the undesirable factors that impinge on the quality of the garment-to-body fit relationship.
- Differentiating between garment body proximity levels for stretch contour fit categories.
- Visualising the stretch fabric distortion characteristics of geometric shapes for transposition and interpretation.
- Implementing a strategy for garment fit analysis.
- Defining the key used to identify the observable stretch deformation in the grid pattern delineated on the analysis garment.

5.4.1 Contour Fit Description

For optimal fit a stretch knit performancewear garment should display no wrinkles have minimal stretch distortion and conform to the body contours to facilitate a range of movement, without displacing or straining the fabric.

Inconsistency exists in current terminology for fit, in the field of stretch knit body garments. Therefore, for clarity and the benefit of this study, differing contour fits have been loosely divided into three categories, each derived from the holding (hugging) power exerted on the body by the retracting stretch fabric. These will be referred to as *Form Fit, Action Fit* and *Power Fit*.

1. **Form Fit** describes garments that conform to a prescribed body posture, have few wrinkles and no stretch other than a minimal amount in specific areas, to allow the fabric to smoothly contour the body. The stretch fabric exerts no pressure on the body and the stretch enables mobility. An example would be close fitting underwear.

2. **Action Fit** describes those garments produced in a diverse range of knit fabrics with different degrees of stretch extension. The stretch characteristics under tension exert some pressure to effectively hold and support the body. Most stretch sportswear comes under this heading.

3. **Power Fit** refers either to the garment as a whole or to specific areas where the pressure exerted by the stretch fabric grips and compresses the flesh, significantly changing the body form shape. Applications cover a wide range of sportswear from aquawear to skiwear and legwear and also form persuasive bodywear worn to mould the body into a desired shape. This type of fit, sometimes referred to as compression stretch, is used extensively for medical applications.

5.4.2 Fitting Scheme

Learning how to fit to an acceptable standard for stretch contoured garments, as with any design development, is a step by step process, building up a store of *basic* knowledge based on practical experience. The fit relationship is complex and fit analysis and evaluation requires simultaneous weighing up of interrelated visual clues. Making a number of fit alterations simultaneously may complicate and confuse the diagnosis of the actual fit problem. Therefore, it is important to adopt a systematic approach of analysis and evaluation.

To establish a method for analysing and evaluating the toile fit, the intrinsic and variable problem areas need to be identified and then prioritised into a fitting scheme. A copy of the working charts used for analysis and evaluation developed from the fitting scheme can be found in Appendix D.

5.4.2.1 Intrinsic problems

The intrinsic problems refer to any inconsistencies in the manufacturing process brought about either by the pattern technology, the fabric behaviour or the garment production techniques or a combination of all these factors. The intrinsic problems are identified as follows:

- Are the seam placements and body landmarks aligned?
- Has a poor cutting technique been used?
- Has there been miss-alignment in the sewing process?
- Are the body measurements accurate?
- Are the draft rules for the body form correct?
- Is the pattern profile correct?
- Does the fabric behave as predicted in terms of stretch?
- Have the variations in fabric pressure been accommodated? (The effects of the radius of curvature can increase fabric pressure and this can become a problem when fabric tension remains constant and the radius gets smaller. As the radii of the body's curved surface diminishes towards the extremities of the hands and feet these areas become subject to greater pressure.)

5.4.2.2 Variable problems

Interrelated areas of the garment are defined either by body landmarks, boundary lines, area relationships or protrusions or a combination of all these factors. The variable problems can be sub-divided as follows:

Bodice (front then back)

- Is the neckline inside or extended away from the natural boundary line?
- Is the shoulder angle aligned with the apex of the shoulder?
- Has adequate provision been made for the bust prominence?
- Has adequate provision been made for the shoulder blades?

- Is the underarm to waist relationship appropriate?

Sleeve Bodice Junction (front and back)

- Is the shoulder angle sleeve relationship at the armscye boundary appropriate?
- Is the bodice aligned and balanced?
- Is the sleeve angle alignment with body appropriate?
- Is the crown depth and the shaping appropriate?
- Is the sleeve alignment with body balanced?
- Does the armhole shape follow the natural arm boundary?

Lower torso (front and back)

- Is the front fork level at the appropriate position?
- Is the front fork point placement aligned appropriately?
- Is the geometry of the crutch towards the front fork point appropriate?
- Is the front leg aligned to the torso appropriately?
- Is the back fork level at the appropriate position?
- Is the back fork point placement aligned appropriately?
- Does the seat geometry toward the back fork point provide adequately for the fabric stretch characteristics?
- Is the back leg aligned to the torso appropriately?

When donning the garment the seams and landmarks are manipulated into position starting at the ankles.

A more representative fit analysis and evaluation is conducted on a subject rather than a dress stand. The assessment takes place after the garment has warmed up and a series of movements, which fully flex the body and the fabric, have been performed. Body heat affects the fibres in fabric causing them to relax and mould to the body. On cessation of movement the fabric adjusts to reach equilibrium in contouring the body, only then is the garment ready for a realistic assessment. Observation of the static toile was achieved to visual advantage when the wearer is standing in a normal upright stance, with the arms positioned at 45° with hands placed on the hips. However, to maintain consistency when visually assess the toile fit the inanimate Dolly (with arms hanging strait) was used in the initial stretch block pattern development process.

The general appearance is then observed, including the girth and seam alignment, the horizontal and vertical balance front and back. Areas where fabric does not follow the intended seamlines and body landmarks are noted. The focus is then on more specific areas, starting with the upper torso at the shoulder, which is observed by sweeping the eyes vertically and horizontally from top to bottom and going around the body viewing the front and back systematically.

5.4.3 Observation of Fabric Stretch Characteristics

In the stretch block pattern development process the fitting scheme was implemented to focus the garment analysis and evaluation. The fabric stretch characteristics were made visible for assessment through delineating the fabric with a 2.5cm grid before the bodysuit was constructed. Observation of the squares illustrated local curvilinear distortion by highlighting:

- the direction of stretch relative to the pattern straight grain line
- the amount of stretch distortion at each square

5.4.3.1 Grid Distortion

The observed shapes should be in the form of squares, rectangles, rhomboids and trapezoids, as illustrated in Figure 102.

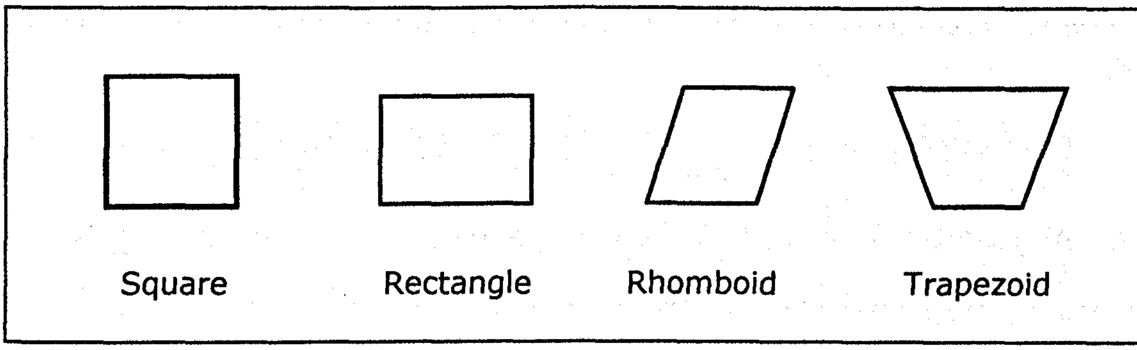


Figure 102– Observable Grid shapes in Visual Analysis

A visual analysis of the toile allows overall assessment of wrinkle and stretch deformation. In this context a *wrinkle* indicates a fabric stretch to body disparity and grid *distortion* identifies the direction and magnitude of localised stretch. In a form fit toile a degree of stretch is unavoidable and this has been defined as Tare Stretch. The predicted stretch visualised by the grid shape deformation is determined by the analysis garment fit level category in Table 9.

Fit Level	Wrinkle	Tare Stretch	Stretch
Form	None	Acceptable	None
Action	None	Acceptable	Predictable
Power	None	Acceptable	Predictable

Table 9 – Fit Level Visual Analysis Key

Observation of the stretch block pattern form fit and action fit in this analysis was achieved when the subject was standing with the arms positioned at 45° and the hands placed on the hips. The fabric for the analysis was delineated with 2.5cm squares and then constructed to contour the body. The ideal body contour stretch toile should not display any wrinkles and should have a minimal number of distorted squares. It is body shape and posture that is the key in the analysis of the stretch garment. An example of the quality of fit and fabric stretch curvilinear distortion characteristics are visually apparent in the grid deformation illustrated in Figures 103, 104 and characterised in Table 10. The geometry of grid distortion changes when the stretch *garment-to-body proximity* relationship becomes closer as the garment pattern is reduced to the required it level.

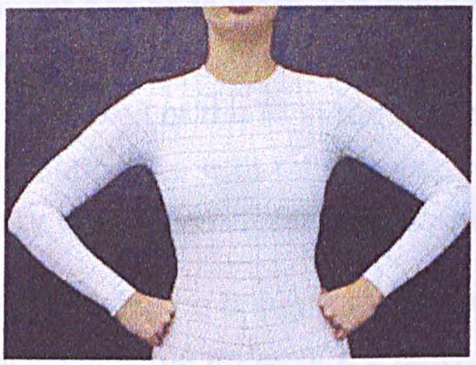


Figure 103- Fiona Action Fit B Front Visual Analysis of Stretch Curvilinear Distortion

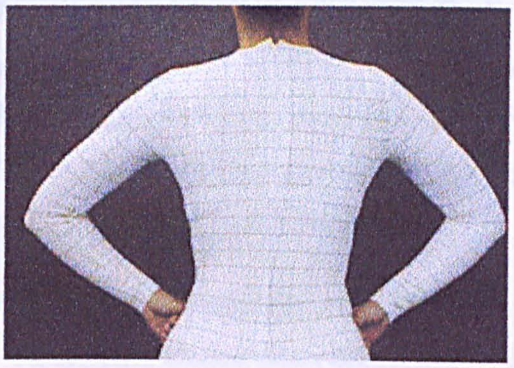


Figure 104- Fiona Action Fit B Back Visual Analysis of Stretch Curvilinear Distortion

Visual Analysis Chart:	**Garment**: Sample Fabric B		**Name**: Fiona	
Area	General	Wrinkle	Tare stretch	Stretch
Front	Very good	None	Minimal	Rectangular
Front armscye and chest	Chest very good, arm good	Unavoidable but minimal underarm	Predictable chest trapezoids	Rectangular chest trapezoids
Back	Very good	None	Predictably rectangular	Rectangular
Shoulder and crown	Very good	None	Rectangular, square at crown	Enlarged squares
Back armscye and shoulder blade	Very good	Unavoidable but minimal underarm	Slight trapezoid lower shoulder blade	Rectangular with rhomboids orientated towards under arm
Comments: Overall fit is very good. The stretch fabric did not require redistribution after movement and a high level of comfort was obtained.				

Table 10- Fiona Bodysuit Fabric Sample B Visual Analysis Chart

5.4.4 Fit Analysis and Implications

Stretch garment analysis is interpretive and the individual's subjective assessment of comfort and fit needs to be considered. The overall fit is assessed including the landmark alignment and seam placement. It is not only the way in which the stretch conforms to grip the body, but how the garment feels, the first impression when donned and impressions once the garment has been worn and subjected to a range of movements that contribute to the quality of the analysis. A detailed analysis and evaluation is undertaken of the fit in the crucial areas to evaluate the implications of its interrelationship with other areas. Some factors that can impact on the quality of the stretch contour garment fit are detailed below:

- Poor fit can be brought about by differences between the right and left sides in some areas of the body. However, these discrepancies, unless excessive, can in most cases be accommodated by the fabric stretch.

- Seam impressions left on the body can give an indication of excessive pressure at a specific site. This can be ascertained by the depth and colour intensity of the skin along the seam impression caused by increased localised pressure.

- Garment-to-body contour frictional resistance occurs when moisture is present on skin or in areas where there are undergarments this can impinge on the fit quality.

- The stretch fit may be affected by grip or anchor points, which restrain the fabric. These anchor or grip points are at the neck, shoulder, hips seat and knee and they are also found at the torso limb junctions of the armpits and the fork level in a body suit or leotard. In leggings with a stirrup they are located at the waist and at the stirrup under the foot, in a top with full-length sleeves the anchor point is the armpit and if the garment is cropped and has an elasticised hem then that also becomes an anchor point.

- Poor fit can be brought about as a consequence of rationalising the pattern profile geometry by approximating the contour into straighter lines and more fluid curves.

- Some knit fabrics, because of the knitted construction, may display *different characteristics between the bias at 45° and at 135° and this* can adversely affect the fit.

5.4.4.1 Fit Quality and Movement

The areas that pose the greatest difficulty in a contoured fit are the torso-limb relationships. The interpretation of fabric geometrical shapes and their stretch characteristics is used subjectively to enhance the contour fit quality whilst providing for ease of mobility and comfort without fabric displacement. When evaluating a garment/pattern as integrated geometrical shapes the potential of the stretch characteristics particularly the bias stretch has great significance in the relationship between body posture encompassing mobility, fit and the pattern profile geometry. The bias stretch characteristic is called upon to assist in contouring the garment in areas of the body where directional changes and protrusion effect the fabric displacement. Examples are in the area around the contour of the armscye which can be affected by the bust and shoulder blades and the area intersecting the torso and leg which can also be affected by the buttocks and the tummy.

Some of the implications of poor fit, exacerbated by mobility, are highlighted in the following examples:

- When the arm is raised, wrinkles appear across the crown and sometimes across the front aligned at the intersection between the armscye and chest as the fabric adjusts to the new body position. Subsequently when the arm is lowered the underarm seam, if it is lower than the natural armscye line, will automatically reposition at the anchor point under the arm. This fixed point does not allow the crown to resume its original position when the arm is lowered. Without physical intervention the shoulder and crown 'poke'; a fold of fabric appears at the crown.

- When the armscye seam placement is encroaching on the front bodice combined with the appearance of a wrinkle of fabric across the front chest, it may indicate that the shoulder angle is at fault or that the armhole is either too deep or an inaccurate shape or that there is too much strain over the bust or it may be a combination of all these factors.

- Wrinkles under the seat towards the fork point and fabric receding between the buttocks could be an indication of an excess of fabric between the side of the body and the fork and an inaccurate seat angle. Fabric strain around the upper thigh can also indicate inaccuracies in the pattern profile at the fork level and seat angles. A combination of all these factors should also be considered when wrinkles and strain are observed in this area.

5.4.4.2 Fit Quality and the Sleeve Crown

The impact of the fabric shape and the implications for the pattern profile geometry in influencing the quality of fit for mobility and comfort is most apparent in the area of the sleeve crown where the predominant geometrical shape would be a trapezoid (a truncated triangle). The apex of the crown is vulnerable to the greatest deformity as the shape of the fabric effects the way in which it deforms. As tension is applied to a triangular shape, it will deform in relation to the forces and this brings about a non-linear stretch characteristic towards the apex of the triangle. Therefore, the construction of the crown should be shallow to allow for the effects of stretch characteristics of the predominant geometrical shape.

Conventionally in a set-in sleeve block pattern the crown is shaped to accommodate the arm when hanging loosely by the side of the body as illustrated in section 4.8.4.2 figure 83. When this type of fit is constructed in a non-stretch fabric this restricts movement as it is impossible to lift up the arm without the fabric straining.

Shirts were designed to allow the arms to be raised easily and to move freely, however, when the arm is lowered there is an excess of fabric under the arm as shown in section 4.8.4.3 Figure 87.

The shape of the shirt pattern profile at the crown is shallow, which is achieved by slashing and spreading the set-in sleeve pattern and as a consequence the crown becomes shallower as the width of the sleeve increases as illustrated in Figure 105. The sleeve torso angle relationship affects the degree of freedom of arm movement.

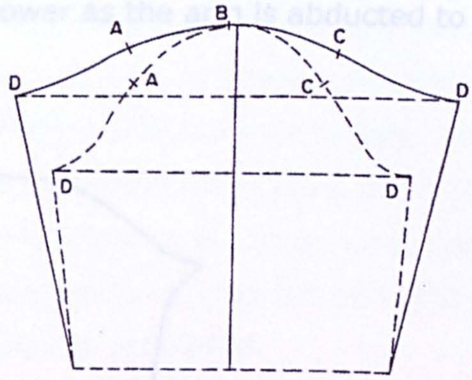


Figure 105- Pattern Manipulation from Set-in Sleeves to Shirtsleeve. Source: Pivnick (1958:58)

In a stretch block, if the crown pattern geometry retains a similar profile to the conventional pattern, where the arm is fully adducted at the neutral anatomical position, with little change in the crown depth, this impairs the quality of the garment fit during movement and when the body is at rest. The disparity in the fit becomes more apparent when the armscye depth is too low and consequently this allows the fabric to ride up to the tie point under the arm during movement. As the arm is lowered a fold of fabric remains at the apex of the crown as illustrated in Figure 106.

Figure 106-Fabric Fold at Crown Apex Scource: Style (1997:42)

When a crown pattern profile similar to a shirt is drafted in a stretch block, the width of the lower sleeve can remain narrow yet still increase in width between the underarm seam junctions (see Figure 107). This effectively reduces the crown depth, bringing the stretch fabric geometry into play. The depth of the crown becomes shallower as the arm is abducted to the movement level envisaged.

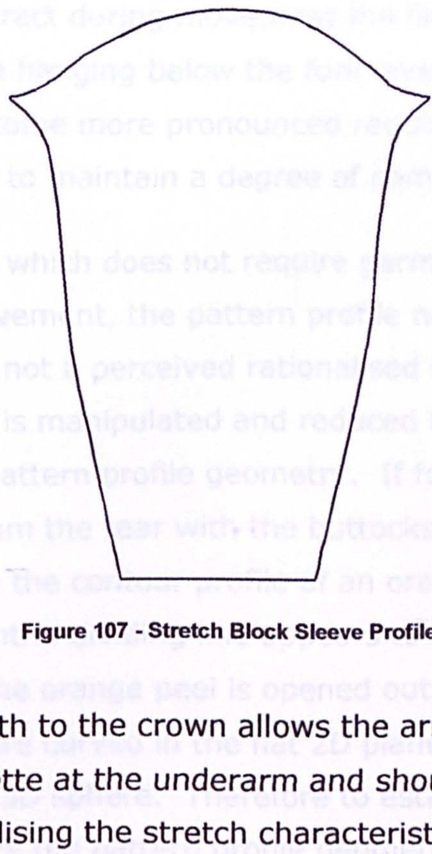


Figure 107 - Stretch Block Sleeve Profile

Adopting a shallow depth to the crown allows the arm to move freely yet retain a smooth silhouette at the underarm and shoulder, during and after movement, through utilising the stretch characteristics. This is illustrated by the garments in Figures 108 and 109.

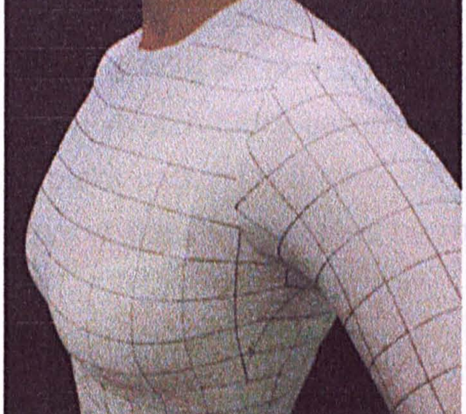


Figure 108-Visual Analysis Front View

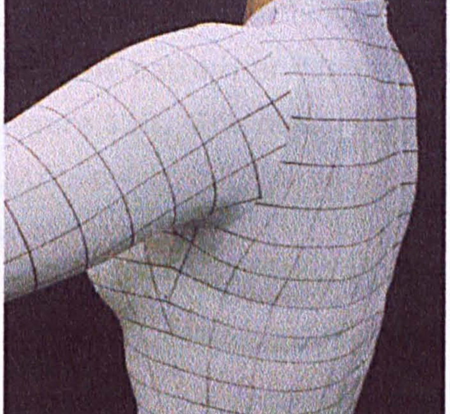


Figure 109- Visual Analysis Back View

5.4.4.3 Fit Quality and the Crutch

Any disparity in the garment-to-body fit quality around the contour of the torso leg area can be the cause of considerable discomfort. If the fabric is restrained at the waist or above and the fork level of the garment is too short and the pattern geometry around the crutch inappropriate, this will cause the fabric to retract between the buttocks. However, if the fabric is not restrained at the waist or above or if the fork level is too long, then as the fabric strains to retract during movement the fabric rides down the leg and assumes a position hanging below the fork level. After movement both these fit disparities become more pronounced requiring the garment to be readjusted to the body to maintain a degree of comfort.

To achieve a fit quality which does not require garment-to-body readjustment after movement, the pattern profile needs to conform to the actual body shape and not a perceived rationalised shape that occurs when a conventional pattern is manipulated and reduced for stretch fabric but without changing the pattern profile geometry. If for comparison the body profile when viewed from the rear with the buttocks divided by a vertical line, is transposed with the contour profile of an orange sphere divided into segments, then the central dividing line appears to be a straight vertical line. However, when the orange peel is opened out it can be observed that the segment sections are curved in the flat 2D plane and this allows the peel to conform to the 3D sphere. Therefore to establish a desirable contour fit quality where the pattern profile geometry conforms to the body profile then the pattern profile geometry must reflect the undulating 3D body contour in the 2D flat pattern geometry. The significance becomes more apparent in comparing a conventional modified trouser block for stretch fabric (see section 3.10.5-3.10.8) with the pattern profile geometry of the new stretch block pattern profile in Figure 110. The fit quality of the stretch block pattern is further enhanced by hollowing out the pattern geometry at the site indicated by the arrow in Figure 110.

This hollowing out process removes the wrinkle that appears under the buttock as a consequence of the converging torso and leg body contour and the bias stretch characteristic, which follows the line of the arrow, is utilised not only to remove the wrinkle but also to allow the fabric to conform to the body during movement without the fabric receding between the buttocks. The curves of the 2D pattern profile geometry around the crutch area allows the fabric to adjust in harmony with the body whilst moving. The resultant 3D garment fit quality of the stretch block analysis toile can be observed in Figures 111 and 112 of Fiona wearing garment B which needed no readjustment to the body during or on cessation of movement.

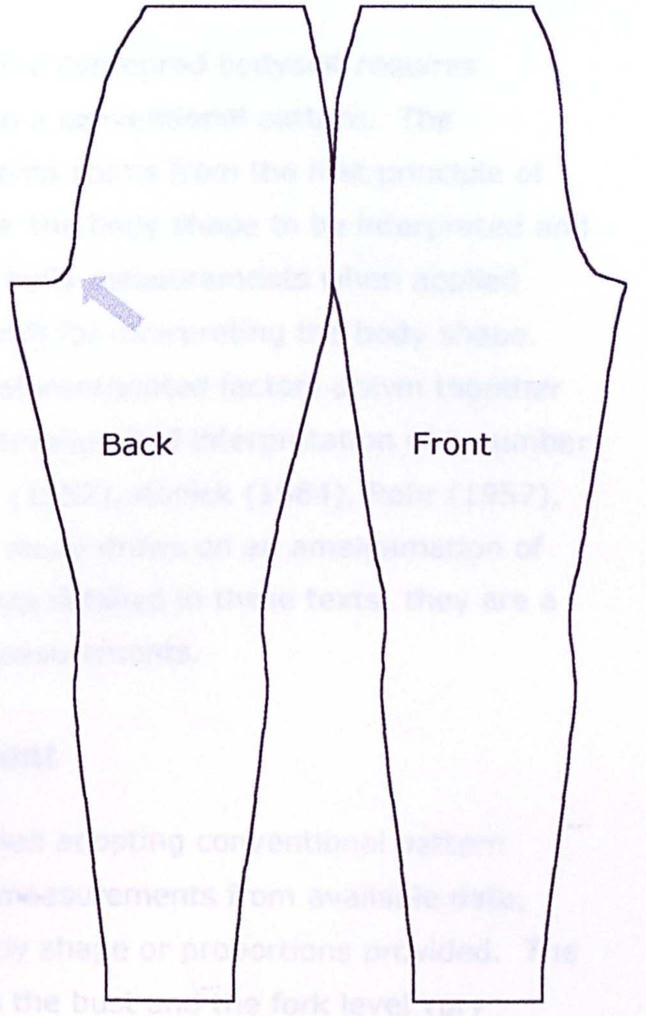


Figure 110 Stretch Block Pattern Profile Lower Torso and Legs

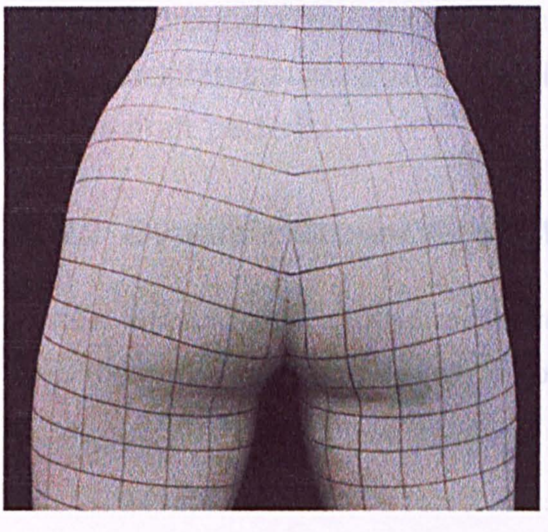


Figure 111 Back View Analysis Garment B

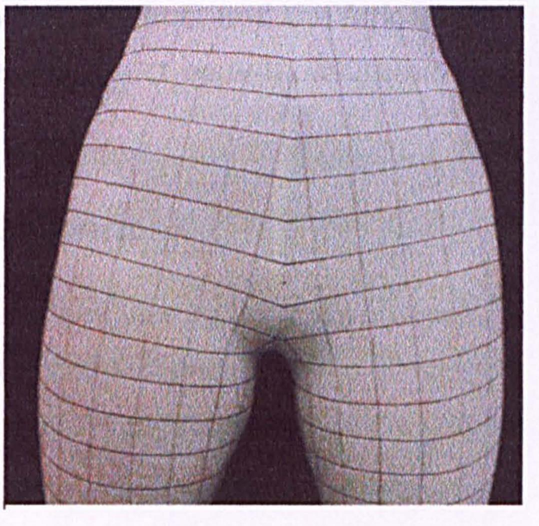


Figure 112 Front View Analysis Garment B

5.5 THE NEW STRETCH BLOCK PATTERN MEASUREMENT

The construction of a block pattern for a contoured bodysuit requires significantly more measurements than a conventional pattern. The rationale for choosing the measurements stems from the first principle of the tailor in keeping in the 'minds eye' the body shape to be interpreted and transposed to the pattern draft. The body measurements when applied directly produce a dynamic pattern draft for interpreting the body shape. They were chosen through cognition of interrelated factors drawn together as a consequence of experience, observation and interpretation of a number of invaluable texts including Kemsley (1957), Kunick (1984), Rohr (1957), and Taylor and Shoben (1990). This study draws on an amalgamation of the landmarks and body measurements detailed in these texts; they are a superset, which include many new measurements.

5.5.1 Somato Width Measurement

The research has highlighted that, when adopting conventional pattern drafting techniques which take body measurements from available data, there is no information relating to body shape or proportions provided. The cross-sectional body profiles between the bust and the fork level vary considerably over a large sample size, but for the purpose of this research a simple algorithm has been proposed to assist in pattern profiling between these levels. Therefore new Somato width measurements, taken with an anthropometer, have been introduced. They assist in defining the shape and proportions of the body contours between the bust and the fork level, which facilitates a more accurate placement of direct body measurements on the draft pattern.

5.5.2 Dynamic Crown Angle Measurement

A new interpretation of the measurement for calculating the crown depth was introduced as a consequence of interrelated factors:

- The dynamic posture adopted by the sports participant during a *particular activity (in this study with arms akimbo at 45°).*
- The increased width of the sleeve at the underarm point as the crown depth is reduced.
- The geometry of the pattern profile which has to be modified to allow for *the fabric stretch characteristics.*

The depth of the crown becomes shallower as the arm is abducted to the movement level envisaged. *The fabric geometry would be inappropriate if* the crown angle depth was maintained with the arm fully adducted at the neutral anatomical position and would result in a pronounced garment–to-*body fit disparity during movement requirements.*

A Dynamic Crown Angle refers to the depth of the crown calculated from the shoulder point at the top of the crown to the intersection between the arm and chest (see Figure 113). With the arms akimbo at 45°, the effective depth $\mathbf{D_c}$ of the crown is reduced $\mathbf{D_{c-r}}$ as the crown angle $\mathbf{Ø_c}$ increases.

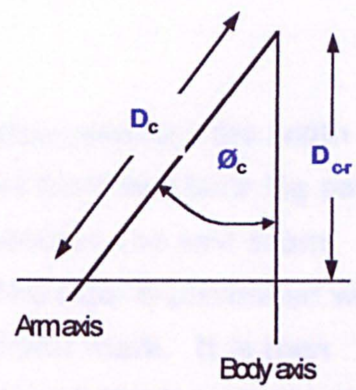


Figure 113- Dynamic Crown Angle

If	Crown Depth	$\mathbf{D_c}$	= 10 mm
	Crown Angle	$\mathbf{Ø_c}$	= 45°
then	Reduced Crown Depth	$\mathbf{D_{c-r}}$	$\mathbf{= D_c * Cos\ Ø_c\ mm}$
			= 10 * Cos (45°) mm
			= 10 *.71 mm
			= 7.1 mm

5.5.3 S-curve

The depth and shape of the body through the crutch from front to back varies considerably. This was not always apparent in a loose fitting conventional trouser pattern draft where the fork point is derived. Therefore a direct measurement was required to establish the fork point for a garment that conforms to the body. The fork point measurement was derived through observation, intuition and frustration with existing method for determining the width from the front to the back at fork level. The factors for consideration are:

- The shape of the body contour
- The pattern profile geometry
- The stretch fabric characteristics

The new S-curve has been introduced to accurately measure the width from the side seam placement to the fork point for the front and back leg pattern profile. The S-curve is taken at the fork level between the side seam placement landmark illustrated in Figure 114. The tape is positioned with the zero on the right leg at the side seam placement mark. It is then passed around the back of the leg and drawn through the legs, taking a reading at the intersection point where the seams converge at the fork level. The tape is then passed around the front of the left leg to the corresponding seam placement landmark, where another reading is taken.

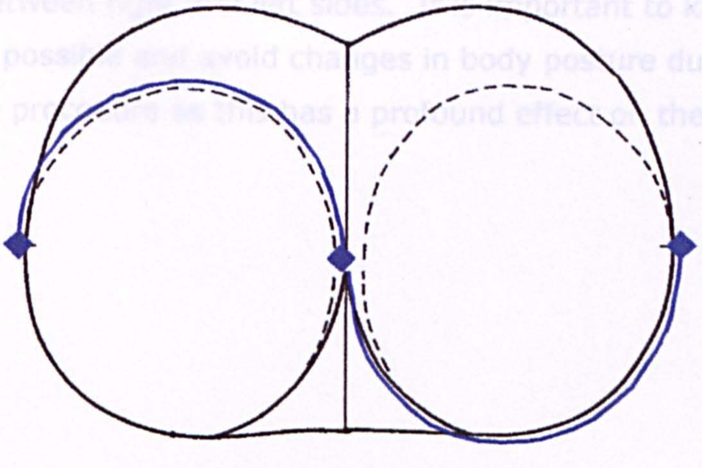


Figure 114 - Placement of S-curve Measurement

To simplify acquiring this measurement, secure the centre of a length of firm tape to the end of a thin piece of doweling. Position the doweling at the fork point and align the tape and mark as indicated in Figure 114 then remove the tape and read off corresponding markings.

5.5.4 Measurement Environment

The measurement environment must be suitably relaxed and warm. Subjects are measured whilst wearing the underwear specific to the stretch toile requirements. A close fitting vest for the subject's comfort requirements is sensible, as the measurement process takes approximately one hour.

The measurement procedure does not follow the convention of measuring only the right side and alternates to suit the measurer and when necessary to accommodate figure variations between sides. Where there were notable differences both sides were measured and adjusted to within stretch potential tolerances.

The body landmarks are positioned prior to the measurement procedure and indicated with crosses, which are applied with a body pencil or a no-trace fabric marker when the landmark coincides with the fabric. Dark elastic cord placed around the landmarks of the bust, under bust, lower rib cage, waist, top hip and hip, present a visual aid to check that the measurements are aligned correctly in the horizontal plane. This also helps with the discrete visualisation of the subject's posture and figure variations including differences between right and left sides. It is important to keep the subject as relaxed as possible and avoid changes in body posture during the measurement procedure as this has a profound effect on the outcome.

At no time was it intended that the garment should be fitted and altered after being constructed directly from the recorded measurements. Therefore, the need for accurate measurements was essential. The positioning of landmarks and measurements to be taken are detailed in the *measurement key in Figures 115-116 and the chart in section 5.5.6.* Care must be taken over the tape tension during the measurement procedure so as not to constrict the flesh.

5.5.5 Body Measurement Key

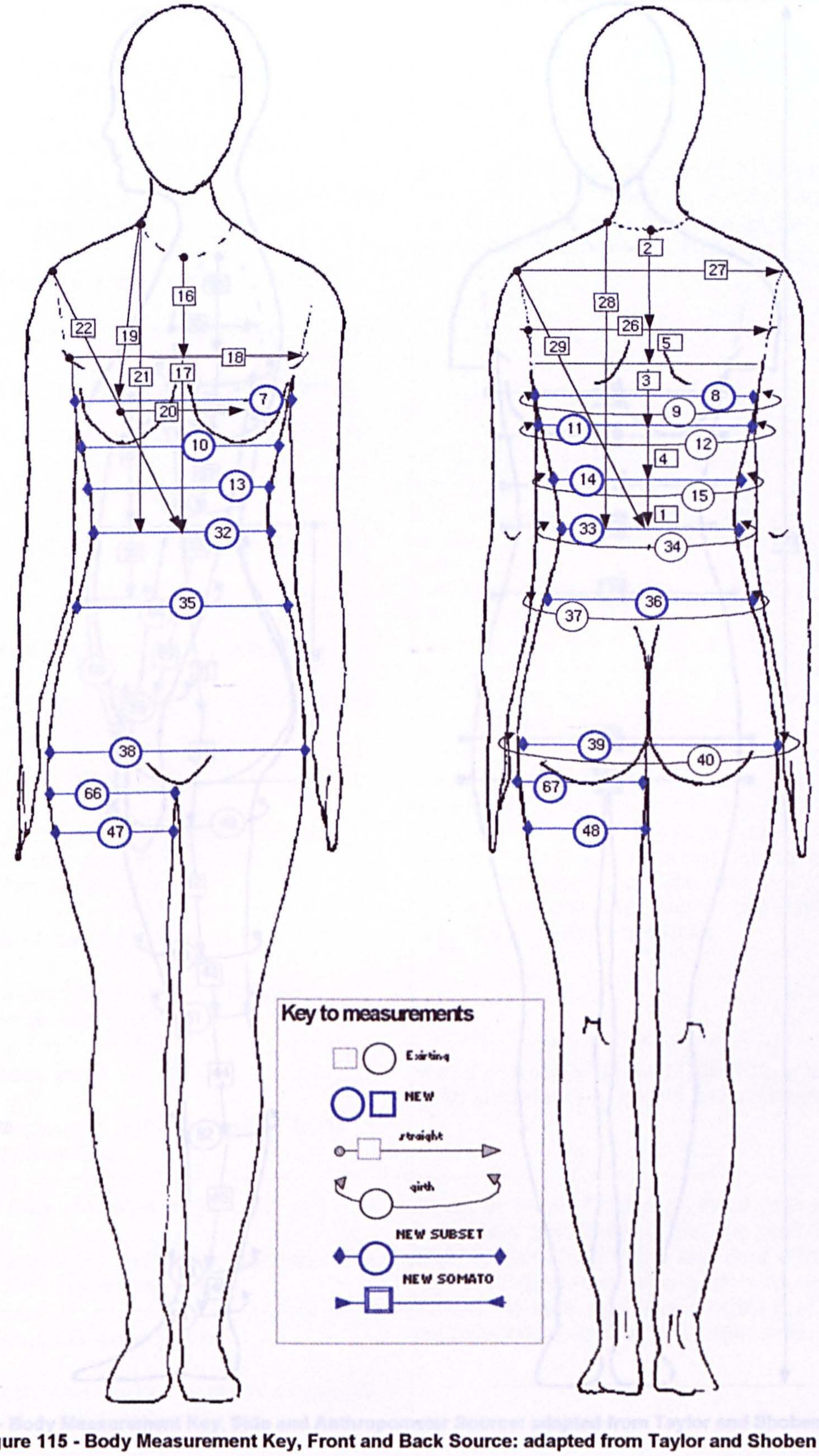


Figure 115 - Body Measurement Key, Front and Back Source: adapted from Taylor and Shoben (1990: 17)

5.5.5 Body Measurement Key

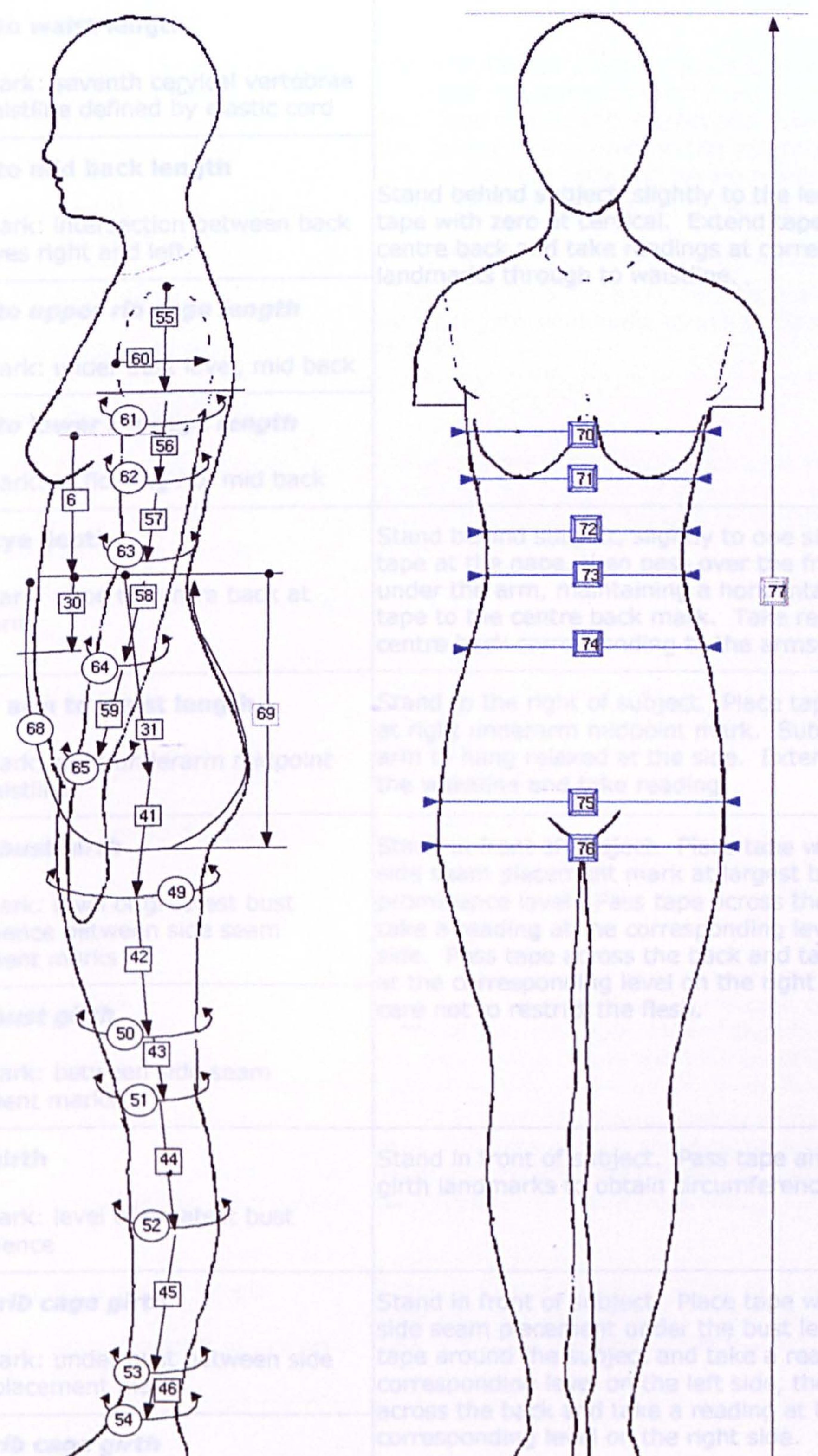


Figure 116- Body Measurement Key, Side and Anthropometer Source: adapted from Taylor and Shoben (1990: 17)

5.5.6 Body Measurement Chart

No.	AREA	METHOD
1	**Nape to waist length** Landmark: seventh cervical vertebrae and waistline defined by elastic cord	Stand behind subject, slightly to the left. Place tape with zero at cervical. Extend tape down the centre back and take readings at corresponding landmarks through to waistline.
2	**Nape to mid back length** Landmark: intersection between back armscyes right and left	
3	***Nape to upper rib cage length*** Landmark: under bust level, mid back	
4	***Nape to lower rib cage length*** Landmark: at floating rib, mid back	
5	**Armscye depth** Landmark: nape to centre back at underarm	Stand behind subject, slightly to one side. Place tape at the nape, then pass over the front shoulder, under the arm, maintaining a horizontal level pass tape to the centre back mark. Take reading at the centre back corresponding to the armscye level.
6	**Under arm to waist length** Landmark: right underarm midpoint and waistline	Stand to the right of subject. Place tape with zero at right underarm midpoint mark. Subject lowers arm to hang relaxed at the side. Extend tape to the waistline and take reading.
7	***Front bust girth*** Landmark: level of greatest bust prominence between side seam placement marks	Stand in front of subject. Place tape with zero at side seam placement mark at largest bust prominence level. Pass tape across the bust and take a reading at the corresponding level on the left side. Pass tape across the back and take a reading at the corresponding level on the right side. Take care not to restrict the flesh.
8	***Back bust girth*** Landmark: between side seam placement marks	
9	**Bust girth** Landmark: level of greatest bust prominence	Stand in front of subject. Pass tape around bust girth landmarks to obtain circumference reading.
10	***Front rib cage girth*** Landmark: under bust between side seam placement marks	Stand in front of subject. Place tape with zero at side seam placement under the bust level. Pass tape around the subject and take a reading at the corresponding level on the left side, then pass tape across the back and take a reading at the corresponding level on the right side.
11	***Back rib cage girth*** Landmark: under bust between side seam placement marks	

12	***Rib cage girth*** Landmark: circumference at under bust level	Stand in front of subject. Pass tape around rib cage girth landmarks to obtain circumference reading.
13	***Front lower rib cage girth*** Landmark: floating rib level between side seam placement marks	Stand in front of subject. Place tape with zero at side seam placement mark at the floating rib level. Pass tape around the subject and take a reading at the corresponding level on the left side, then pass tape across the back and take a reading at the corresponding level on the right side.
14	***Back lower rib cage girth*** Landmark: floating rib level between side seam placement marks	
15	***Lower rib cage girth*** Landmark: floating rib level	Stand in front of subject. Pass tape around lower rib cage girth landmarks to obtain circumference reading.
16	***Neck base to chest length*** Landmark: intersection between arm and chest	Stand in front of subject. Place tape with zero at front neck base and extend tape to take readings at corresponding levels through to waistline at centre front point.
17	**Neck base to waist length** Landmark: neck pit and waistline at centre front	
18	**Front across chest** Landmark: front armscyes at intersection between arm and chest	Stand in front of subject. Place tape with zero at right armscye mark and extend horizontally across the chest and take reading at the corresponding level at left armscye mark.
19	**Shoulder at neck to bust point length** Landmark: shoulder line intersection at neck and bust level	Stand in front of subject, slightly to the right. Place tape with zero at the intersecting shoulder line and neck base line. Extend tape over the right breast to the centre nipple and take reading.
20	**Bust point width** Landmark: centre nipples	Stand in front of subject. Place tape with zero at landmark of right bust, extend tape horizontally to left bust centre nipple and take reading.
21	**Front shoulder height to waist length** Landmark: shoulder line, intersection at neck to waistline	Stand in front of subject, slightly to the right. Place tape with zero at right shoulder neck boundary mark and extend tape parallel to centre front and take reading at centre front waist.
22	**Front shoulder angle length** Landmark: shoulder point at armscye to centre front waist	Stand in front of subject. Place tape with zero at right shoulder point mark, extend tape diagonally to centre front at waist and take reading.

23	**Neck base girth** Landmark: nape and base of neck	Stand behind subject. Place tape with zero at nape, and then pass around the neck base. Move around the subject keeping tape in position without constriction taking a reading at the nape on completing circuit of the neck base.
24	**Front between shoulder points** Landmark: Dimple at shoulder point site located when arm is abducted and marked when adducted, left and right	Stand in front of subject. Place tape with zero at the right shoulder point mark and extend horizontally across the front to the left shoulder point and take reading.
25	**Shoulder length** Landmark: neck base along shoulder line at intersection with armscye	Stand behind subject's right shoulder. Place tape with zero at the neck base and pass along the shoulder line. Take reading at the intersection of armscye with shoulder line.
26	**Back across shoulder** Landmark: back armscyes at intersection between arm and torso	Stand behind subject. Place tape with zero at the left armscye mark and extend horizontally across the back to the right armscye mark and take reading.
27	**Back between shoulder points** Landmark: Dimple at shoulder point site located when arm is abducted and marked when adducted, left and right	Stand behind subject. Place tape with zero at the left shoulder point mark and extend horizontally across the chest to the right shoulder point and take reading.
28	**Back shoulder height to waist length** Landmark: shoulder line, intersection at neck waistline	Stand behind subject, slightly to the left. Place tape with zero at lerf shoulder neck mark extend tape parallel to centre back waistline and take reading.
29	**Back shoulder angle length** Landmark: shoulder point at armscye to centre back waist	Stand behind subject. Place tape with zero at left shoulder point mark, extend tape diagonally to centre back at waist and take reading.
30	***Waist to top hip length at side*** Landmark: waistline and iliac crest on right side seam placement marks	Squat on right side of subject. Place tape with zero at the waistline and extend to hip level taking readings at corresponding landmarks through to hip level.
31	**Waist to hip length at side** Landmark: waistline and top hip level at greatest seat prominence on right side seam placement marks	
32	***Front waist girth*** Landmark: waist between side seam placement marks	Stand in front of subject. Place tape with zero at side seam placement mark at the waist level. Pass tape across front waist and take reading at the corresponding level on the left side. Then pass the tape across the back and take reading at corresponding level on the right side.
33	***Back waist girth*** Landmark: waist between side seam placement marks	

34	**Waist girth** Landmark: waist at elastic cord level	Stand in front of subject. Pass tape around waist girth at landmarks to obtain circumference reading.
35	***Front top hip girth*** Landmark: level at greatest abdominal prominence at iliac crest between side seam placement marks	Stand in front of subject. Place tape with zero at seam placement mark at the top hip girth landmarks. Pass tape across front top hip and take reading at the corresponding level on the left side. Then pass the tape across the back and take reading at a corresponding level on the right side.
36	***Back top hip girth*** Landmark: level at iliac crest between side seam placement marks	
37	**Top hip girth** Landmark: level at iliac crest	Stand on the right side of the subject. Pass tape around top hip at landmarks to obtain circumference reading.
38	***Front hip girth at widest part*** Landmark: level at greatest seat prominence between side seam placement marks.	Stand in front of subject. Place tape with zero at seam placement at the hip girth. Pass across front hip and take reading at the corresponding level on the left side. Pass tape across the back and take reading at a corresponding level on the right side.
39	***Back hip girth at widest point*** Landmark: level at greatest seat prominence between side seam placement marks	
40	**Hip girth** Landmark: level at greatest seat prominence	Stand on the right side of subject. Pass tape around the hip girth at landmarks to obtain circumference reading.
41	***Waist to thigh length*** Landmark: at side seam placement mark	Squat at right side of subject. Place tape with zero at waistline on right side, hanging perpendicular to the floor. Take readings at the corresponding landmarks through to the ankle.
42	***Waist to above knee length*** Landmark: above kneecap at narrowest point at side seam placement mark	
43	**Waist to knee length** Landmark: kneecap at side seam placement mark	
44	***Waist to calf length*** Landmark: widest point at side seam placement mark	

45	**Waist to above anklebone length** Landmark: waistline to tapered part above anklebone	Squat at right side of subject. Place tape with zero at waistline on right side, hanging perpendicular to the floor. Take readings at the corresponding landmarks through to the ankle.
46	**Waist to ankle bone length** Landmark: waistline to anklebone at side seam placement mark	
47	***Front thigh girth*** Landmark: at widest point between side seam placement marks	Squat at right side of subject. Place tape with zero at the side seam placement mark at the thigh. Pass tape across front thigh and take reading at the corresponding inner thigh level. Then pass tape across the back thigh and take a reading at corresponding level at the outer thigh.
48	***Back thigh girth*** Landmark: at widest point between side seam placement marks	
49	**Thigh girth** Landmark: at widest point	Squat at right side of subject of subject. Pass tape *around thigh girth at landmarks to obtain* circumference reading.
50	***Above knee girth*** Landmark: above kneecap at narrowest point	Squat at right side of subject. Pass tape around the above knee girth at landmarks to obtain circumference reading.
51	**Knee girth** Landmark: kneecap	Squat at right side of subject. Pass tape around knee girth at landmarks to obtain circumference reading.
52	**Calf girth** Landmark: at widest point	Squat at right side of subject. Pass tape around calf girth at landmarks to obtain circumference reading.
53	**Above ankle girth** Landmark: tapered part of ankle	Squat at right side of subject. Place tape around narrowest part of ankle to obtain circumference reading.
54	**Ankle girth** Landmark: anklebone	Squat at right side of subject. Place tape around the anklebone with sufficient tension to maintain its position over the irregular contours of the ankle.
55	***Crown depth*** Landmark: shoulder point to intersection between arm and torso back and front	Stand on right side, slightly to the rear of subject. Subject's arm is at 45^{o} with hand resting upon the hip. Place tape with zero at the shoulder point landmark and extended to landmark and take reading.
56	***Shoulder point to bicep length*** Landmark: shoulder point to bicep at widest point	Stand on right side, slightly to the rear of subject. Subject's arm hangs loosely by the side with palm facing the body. Place tape with zero at the shoulder point landmark and extended to landmark at bicep and take reading.

57	**Shoulder to elbow length** Landmark: shoulder point and elbow	
58	***Shoulder point to forearm length*** Landmark: shoulder point and widest point of forearm	Stand on right side, slightly to the rear of subject. Subject's arm hangs loosely by the side with palm facing the body. Place tape with zero at the shoulder point landmark and extended to landmark at wrist. Take readings at corresponding landmarks through to the distal end of ulna.
59	**Shoulder point to wrist length** Landmark: shoulder point and wristbone	
60	**Crown width** Landmark: crown level at intersection between arm and torso back and front	Stand on right side of the subject. Place tape with zero at the back torso intersection, extend tape horizontally across upper arm and take reading at corresponding landmark at the front.
61	**Upper arm girth** Landmark: intersection between arm and torso back and front	Stand on right side, slightly to the rear of the subject. Pass tape around upper arm girth at landmarks to obtain circumference reading.
62	**Bicep girth** Landmark: upper arm at widest point	Stand on right side, slightly to the rear of the subject. Pass tape around bicep girth at landmarks to obtain circumference reading.
63	**Elbow girth** Landmark: elbow	Stand on right side, slightly to the rear of the subject. Pass tape around elbow girth at landmarks to obtain circumference reading.
64	***Forearm girth*** Landmark: lower arm at widest point	Stand on right side, slightly to the rear of the subject. Pass tape around forearm girth at landmarks to obtain circumference reading.
65	**Wrist girth** Landmark: wristbone	Stand in front of subject. The subject extended her forearm with the palm pronated. Place tape around the wrist with sufficient tension to maintain its position over the irregular contours of the wrist.
66	***S front fork level*** Landmark: Fork level at side seam placement mark to fork point intersection	Stand in front of subject. Place tape with the zero at right side seam placement mark and pass around the back of the leg. Draw the tape through the legs and take a reading at the fork point (the intersection where the seams converge at fork level) Pass the tape around the front of the other leg to the corresponding seam placement landmark and take reading.
67	***S back fork level*** Landmark: fork point intersection to under the fork level at the side seam placement mark	

68	**Crutch length** Landmark: centre waist front to centre waist back	Stand behind the subject. Subject to place tape with zero at centre front waistline. Extend tape centrally through the fork level until resistance is felt and continue up to centre back waist level.
69	**Body rise (waist to fork level)** Landmark: waistline on right side, seated position	Stand on right side of subject. Seat subject on a flat, firm, horizontal surface, with trunk erect and right arm folded across the chest. Place tape with zero at waistline on right side and extend it downwards perpendicular to the seat level and take reading.
70	***Bust Somato width*** Landmark: level at greatest bust prominence between side seam placement marks	
71	***Rib cage Somato width under bust*** Landmark: level at under bust between side seam placement marks	
72	***Lower rib cage Somato width*** Landmark: level at floating rib between side seam placement marks	
73	***Waist Somato width*** Landmark: level at waist between side seam placement marks	Stand in front of subject. Position anthropometer in the horizontal plane and take readings at the corresponding side seam placement landmarks. Place anthropometer against subject without constricting the flesh.
74	***Top hip Somato width*** Landmark: level at iliac crest between side seam placement marks	
75	***Hip Somato width*** Landmark: level at greatest seat prominence between side seam placement marks	
76	***Fork level Somato width*** Landmark: Fork level at torso and leg junction between side seam placement marks	
77	**Height** Landmark: top of head	Subject stands in the anatomical position with the eyes directed forward at their own level. Measurer stands at rear of subject, slightly to the left. The arm of the anthropometer is pulled down to touch the top of the head and a reading is taken.
78	**Weight**	This is included to determine a height weight ratio.

5.6. THE NEW STRETCH BLOCK PATTERN DRAFT

The stretch block pattern is constructed in five sections: the front bodice; the back; the front legs; the back legs and the sleeve. The block pattern in this study is constructed without a seam allowance.

The seam placement for a block pattern follows a vertical line dividing the right and left of the torso down the centre front and centre back. The division between the front and back body is aligned at the apex of the shoulder and side seam placement is balanced to divide the front and back torso from the shoulder apex, the legs and inside arm. The armhole and neckline follow natural boundary lines of the body, as do the sleeve and leg, which finish just below the wrist and ankle bone.

The sleeve is constructed in a single piece and is aligned with the side seam at the underarm. The crown and under arm seam follows the armscye line around the natural boundary between arm and torso. The apex of the crown is aligned with the shoulder seam. The front and back sleeve pitch balance points should align with the corresponding balance points on the bodice at the intersections between the arm and chest.

Measurements taken directly from the body are used to draft the new stretch block pattern. However, measurements are moved to enhance the quality of the garment fit by altering the pattern profile to utilise the potential of the fabric stretch characteristics in contouring the body to accommodate protrusions at the bust and seat. The dynamics of bias stretch characteristic are employed to assist in contouring the garment in areas of the body where directional changes and protrusion effect the fabric displacement. The potential of the bias stretch characteristic has been applied subjectively as the bias stretch cannot be quantified for specific areas. The pattern profile geometry was adjusted by 1cm on the pattern draft for the lower torso and legs at the seat angle draft sequence 19, which hollowed out the seat curve in the area between the buttocks. This was implemented to eliminate excess fabric under the buttock, which would have resulted in the fabric receding into the seat cleavage. The pattern profile of the front bodice at the side seam and lower portion of the armhole has also been adjusted utilising the stretch potential to improve the garment fit quality around the underarm and over the bust protrusion. This utilisation of the bias stretch contributes to the elimination of fabric displacement during and after cessation of movement.

5.6.1 Somato Width Calculation

Body widths are the starting point for apportioning the circumference measurements and are taken with an anthropometer.

Somato width measurements are taken from the bust through to the fork level. The widest measurement was selected, (either the hip, the fork or the bust level) and the remaining widths subtracted, this is repeated at all other levels, including the upper body, to obtain a body contour profile.

A line parallel to the centre line is taken outside the body, which then becomes the pattern draft vertical axis. The greatest somato width is aligned on the vertical axis. The calculated Somato Offsets (SO) are then positioned. Girth measurements are then apportioned to the somato offsets along the vertical axis.

- All somato widths (SW) are taken using an anthropometer
- The widest somato width becomes the reference for all somato offsets (SO), the pattern profile at this landmark will meet the axis
- The SO at other landmarks must be calculated individually

$$SO_n = \frac{SW_w - SW_n}{4}$$

Where SO_n = Somato Offset at landmark n

SW_w = The widest somato width

SW_n = Somato width at landmark n

5.6.2 The Reduction Factor

The form fit stretch block pattern has to be reduced to the required fit level category, which for this study is the action fit level. All body measurements have to be reduced before an action fit stretch block pattern can be drafted. Reduction takes place on the horizontal and vertical plane.

The pattern orientation is crucial in stretch performance for mobility and fit in a fabric that has differing bi-directional stretch. Although there is no consensus, personal experience ratified by this research found that the direction of maximum stretch placed the length of the body, optimised the stretch potential to accommodate maximum body expansion. With this in mind the reduction factor applied in the course and wale direction of the fabric is vital. The reduction factor is consistent with retaining the stretch extensibility in the region of the low modulus, which maximises the directional stretch potential.

The amount of reduction in the course and wale directions has two components. However, the fabric has multi-directional stretch characteristics, which are utilised in contouring the body. The bias stretch contributes to fabric movement in the course and wale directions, as previously discussed. A true picture of the stretch extension cannot be gained by measuring in the two directions of stretch extension only. Therefore, it was vital to quantify this multi-directional stretch extension and apportion the stretch extension factor between the two components of the course and wale. The simplest way to achieve this was to quantify the bias stretch extension and average the stretch extension value between the course and wale stretch values. For this purpose a Quad Angle Plot and the concept of a Bias Vector has been introduced.

The Quad Load Test provided stretch values in the three orientations originally and was subsequently extended to include the two bias orientations of 45° and 135° to give a greater understanding of the angular distribution of the fabric stretch characteristics. An averaged value should be taken of the 45° and 135° bias fabric samples when minimal differences occur between the two bias directions. As small discrepancies accommodated within the stretch tolerance are acceptable. The original stretch values of the course, wale and 45° bias, required interpretation to propose a method of apportioning the orientation reduction, which was derived through a combination of experimentation and experience, this variable is defined as the Axis Ratio.

The pattern orientation aligns the length of the body in the direction of maximum stretch extension determined by the quad load test course and wale measurements only, this is because the stretch block pattern would not usually be orientated in the bias direction on the fabric.

Enhancing the fit for maximum comfort during and after cessation of movement, without straining the fabric, is a function of the pattern orientation and the pattern reduction factor, which must confine the stretch extension to the low modulus region, for the appropriate fit level category.

5.6.2.1 The Reduction Factor Allocation

The amount by which the form fit pattern will be reduced in the course and wale directions is a function of:

- **Quad load test** The fabric extension measurement in the course, wale and 45° and 135° bias orientation.
- **Fabric bias vector** The average of the course and bias and the wale and bias extension measurement.
- **Axis ratio** The apportionment of the amount of available stretch applied to the pattern in the vertical and horizontal directions.
- **Fit factor** The amount of the available stretch to be used by the different fit level categories form fit, action fit and power fit.

All of the following sample calculations are to 0 d.p. (zero decimal places), use Fabric **B** and an **Action** fit factor.

5.6.2.2 Quad load test

The Quad Load Test is for calculating the degree of fabric stretch extension to determine a stretch reduction factor. The method calculates the degree of stretch extension of fabric samples measuring 5cm x 20cm, with 10cm benchmarks at a specific load of 250g in the four fabric orientations of course, wale and bias 45° and 135°. The test sample is placed on the hanger and the 250g weight applied. After allowing the fabric to stabilise for one minute, the extended measurement between the benchmarks is recorded in Table 11 (a copy of Table 6 in section 2.8.4.1).

Code	Quality	Description	Course	Wale	45° Bias	135° Bias
A	21649	32gg 210g Coolmax/Lycra	136	128	140	135
B	21132	32gg 260g Animalmax	156	120	145	145
C	21132	32gg 260g Animalmax	152	132	153	148
D	22203	56gg 220g Coomax/T902 Triskin	118	110	115	114
E	21130	32gg 180g Coolmax/Lycra	150	128	157	147

Table 11- Quad Load Test Results (a copy of Table 6 in section 2.8.4.1)

The degree of stretch expressed as a percentage is calculated by subtracting the relaxed length from the extended length and then dividing the result by the relaxed length.

$$\text{Degree of stretch} = \left(\frac{\text{extended length} - \text{relaxed length}}{\text{relaxed length}}\right)\%$$

The calculation for the degree of stretch extension expressed as a percentage is simplified because the benchmark relaxed length of a 100mm was chosen. Therefore the percentage is calculated simply by subtracting 100 from the extended length and the result is the stretch expressed as a percentage.

For example sample B in the course direction, coded BC

Degree of stretch S = 145 – 100

= 45%

The results from the quad load test showing the degree of extension are then are recorded in Table 12

Hanger Load Test			
Fabric Sample	**Course c%**	**Wale w%**	**Bias b%**
A	36	28	40
B	**56**	**20**	**45**
C	52	32	53
D	18	10	15
E	50	28	57

Table 12 –Hanger Laod Test Results

5.6.2.3 Fabric bias vector

The hanger load tests have to be interpreted to propose a stretch reduction theory. This is achieved by analysing the angular stretch distribution curve characteristic for Sample B, onto which has been superimposed bias vectors (see Figure 117).

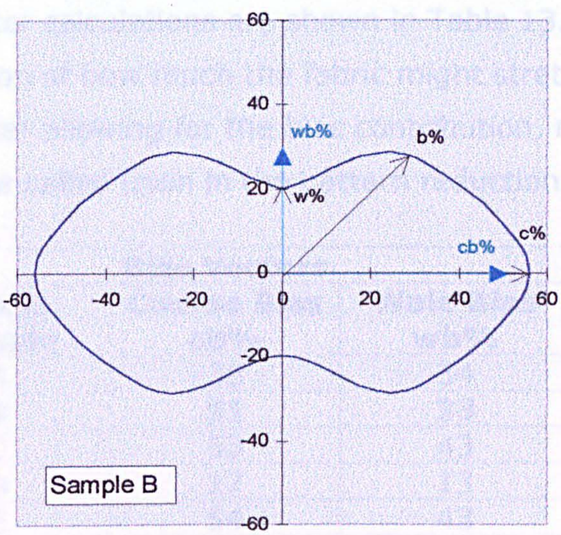


Figure 117 - Bias Vectors

There are a number of ways in which these vectors could have been defined but in this study an average has been taken of the course and bias and the wale and bias extension measurement by adding the two measurements together and then dividing the result by two.

The following examples are the course bias vector and the wale bias vector with the calculations for fabric sample B:

Course bias vector cb% $= \left(\dfrac{c\% + b\%}{2}\right)\%$

for example **cb%** $= \left(\dfrac{56 + 45}{2}\right)\%$

$$\mathbf{= 51\ \%}$$

and

Wale bias vector $wb\% = \left(\frac{w\% + b\%}{2}\right)\%$

$$\mathbf{wb\%} = \left(\frac{20 + 45}{2}\right)\%$$

$$\mathbf{= 33\ \%}$$

The resulting bias vector calculations are shown in Table 13. Although the values give an indication of how much the fabric might stretch in the course and wale directions after allowing for the bias contribution, not all of the available stretch will be called upon in the pattern reduction.

Bias Vectors		
Fabric Sample	**Course Bias cb%**	**Wale Bias wb%**
A	38	34
B	**51**	**33**
C	53	43
D	17	13
E	54	43

Table 13 - Bias Vectors

5.6.2.4 Axis Ratio

The axis ratio takes into account the pattern orientation of the reduced pattern profile on the stretch fabric. Provided that the fabric stretch extension exceeds that of body expansion through movement and that the available stretch to be utilised is retained in the low modulus region. Then to achieve optimum fit to enhance comfort and mobility the length of the garment is orientated in the direction of maximum stretch, this alignment is the direction of maximum elongation for both. The amount by which the fabric is reduced in the direction of maximum stretch (the length of the body) is usually less than the direction of minimum stretch (the circumference of the body) this pattern orientation allows the fabric to retract and extend in unison with the body like a second skin.

The incorporation of an axis ratio table within the computer model enabled the ratio to be quantified (see Table 14). *Using an axis ratio of 7:2* produced a pattern in keeping with personal experience of stretch garment behaviour.

Axis Ratio	
Course **Ac**	2
Wale **Aw**	7

Table 14 - Axis Ratio

To calculate the *axis ratio reduction* the *axis ratio value* is divided by the result of addition of the course axis and the wale axis together, the bias vector then multiplies this combined value.

The axis reduction ratio applied to the bias vector calculations the resulting percentage stretch reductions in the course and wale directions (see Table 15) are calculated as follows:

Course axis reduction $$Rc\% = \left(\frac{Ac}{Ac + Aw}\right) * cb\ \%$$

For example $$\mathbf{Rc\%} = \left(\frac{2}{2+7}\right) * 51\ \%$$

$$\mathbf{= 11\%}$$

and

Wale axis reduction $$Rw\% = \left(\frac{Aw}{Ac + Aw}\right) * wb\ \%$$

$$\mathbf{Rw\%} = \left(\frac{7}{2+7}\right) * 33\ \%$$

$$\mathbf{= 25\%}$$

Axis Reduction		
Fabric Sample	**Course % Reduction**	**Wale % Reduction**
A	8	26
B	**11**	**25**
C	12	33
D	4	10
E	11	31

Table 15 – Axis Reduction

5.6.2.5 Fit Factor

When developing a pattern suitable for stretch applications the *form fit* should ideally not stretch. At the other end of the scale a power fit requires significant forces to be exerted on the body. The fit factor (see Table 16) allows the model to produce patterns suitable for a number of contour fit levels, but this was limited to form fit and action fit level in this study.

Fit Level	Fit Factor FF
Form	0.00
Action	**0.75**
Power	1.00

Table 16 – Fit Factor

5.6.2.6 Reduction Factor

The reduction factor is calculated by dividing 100 by 100 plus the multiplication of the axis reduction percentage (course or wale) by the fit factor. The overall reduction of the pattern is applied in both the course and wale directions.

The axis reduction percentage and the fit factor are combined and the resulting stretch block pattern reduction factor in the course or wale is calculated as follows:

Course reduction factor RFc $= \dfrac{100}{100+(Rc\% * FF)}$

for example **RFc** $= \dfrac{100}{100+(11*.75)}$

= 0.92

Wale reduction factor RFw $= \dfrac{100}{100+(Rw\% * FF)}$

RFw $= \dfrac{100}{100+(25*.75)}$

= 0.84

The final reduction factors are recorded in Table 17.

Reduction Factor		
Sample	**RFc**	**RFw**
A	0.94	0.83
B	**0.92**	**0.84**
C	0.92	0.80
D	0.97	0.93
E	0.92	0.81

Table 17 - Reduction Factor

5.6.2.7 Reduction Factor Table

The sample calculations may at first sight appear somewhat daunting to the designer, and might be more appealing to the scientist. Therefore, to assist with manually drafting the stretch pattern a simplified method of directly reducing the stretch block form fit pattern draft calculations has been developed.

The Reduction Factor Table for the course/bias and wale/bias (see Tables 18 and 19) have been compiled for a given Axis Ratio of 7:2 and an Action Fit Factor of 0.75. The hanger load test provided the input values for course, wale and bias stretch. The reduction factors can be read directly from the table without the need for any calculations whatsoever.

Using the worked examples for Sample B, the Hanger Load Test gives stretch values of course=56%, wale=20% and bias=45%. From Table 18 this corresponds to a course reduction=8% and a wale reduction=16% which expressed as factors are 0.92 and 0.84 respectively.

		BIAS											
		3-7	8-12	13-17	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62
	3-7	1	1	2	2	2	3	3	4	4	4	5	5
	8-12	1	2	2	2	3	3	4	4	4	5	5	6
C	13-17	2	2	2	3	3	4	4	4	5	5	6	6
	18-22	2	2	3	3	4	4	4	5	5	6	6	6
O	23-27	2	3	3	4	4	4	5	5	6	6	6	7
	28-32	3	3	4	4	4	5	5	6	6	6	7	7
U	33-37	3	4	4	4	5	5	6	6	6	7	7	7
R	38-42	4	4	4	5	5	6	6	6	7	7	7	8
	43-47	4	4	5	5	6	6	6	7	7	7	8	8
S	48-52	4	5	5	6	6	6	7	7	7	8	8	8
	53-57	5	5	6	6	6	7	7	7	8	8	8	9
E	58-62	5	6	6	6	7	7	7	8	8	8	9	9

Table 18- Reduction Factor Chart - Course/Bias

		BIAS											
		3-7	8-12	13-17	18-22	23-27	28-32	33-37	38-42	43-47	48-52	53-57	58-62
	3-7	3	4	6	7	8	9	10	12	13	14	15	16
	8-12	4	6	7	8	9	10	12	13	14	15	16	17
	13-17	6	7	8	9	10	12	13	14	15	16	17	18
	18-22	7	8	9	10	12	13	14	15	16	17	18	19
W	23-27	8	9	10	12	13	14	15	16	17	18	19	20
A	28-32	9	10	12	13	14	15	16	17	18	19	20	21
	33-37	10	12	13	14	15	16	17	18	19	20	21	22
L	38-42	12	13	14	15	16	17	18	19	20	21	22	23
	43-47	13	14	15	16	17	18	19	20	21	22	23	23
E	48-52	14	15	16	17	18	19	20	21	22	23	23	24
	53-57	15	16	17	18	19	20	21	22	23	23	24	25
	58-62	16	17	18	19	20	21	22	23	23	24	25	26

Table 19 - Reduction Factor Chart - Wale/Bias

5.6.2.8 Stretch Band Coding

The fabric reduction table has been laid out in bands by rounding up and down the reduction percentage values to the nearest 5%. This is illustrated in Table 20, which shows a Stretch Band Colour Coding ranging from 0% to 25% in steps of 5%. A 5% band was chosen because it offered a reasonable number of bands within the working range of up to 30% stretch reduction.

Band Number and Colour			Range %	Reduction %
1	White		0 – 2.4	0
2	Red		2.5 – 7.4	5
3	Orange		7.5 – 12.4	10
4	Yellow		12.5 – 17.4	15
5	Green		17.5 – 22.4	20
6	Blue		22.5 -	25

Table 20 – Stretch Band Colour Coding

Fabric B for example has a course stretch of 56% and a bias stretch of 45% which results in a course reduction of 8% which falls into the 10% band. The corresponding wale stretch of 20% results in a 16% wale reduction which falls within the 15% band.

5.6.2.9 Stretch Scale Rule

An extruded aluminium scale rule having a triangular cross section could be produced (see Figure 118). It should be 1 metre in length and have 6 scales in line with the stretch band coding. It should also be colour coded to minimise user error. The colour-coded band allows the selection of a corresponding reduction colour on the Stretch Scale Rule, which in this example would be orange and yellow respectively.

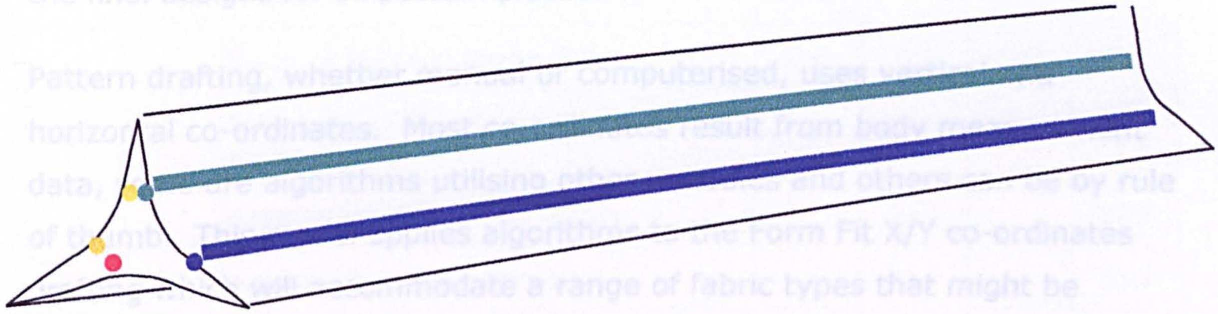


Figure 118 – Stretch Scale Rule

5.6.2.10 Reduction Factor in Brief

The stretch block pattern reduction in essence is the reducing of the pattern profile vertically and horizontally by a proportion of the available directional stretch extension this combined with the orientation of the pattern maximises the stretch potential. To calculate the reduction factor the amount of the available stretch is determined by the quad load test fabric samples from the course, wale and bias orientations. The quad load test results are reduced to two values by averaging the course/bias and wale/bias, the bias vectors. The bias vectors calculate the directional stretch available to be applied to the stretch block pattern for the different fit levels (form, action or power fit). The fit factor (fit level value) suggests the amount of the available directional stretch to be applied by the axis ratio, which is the different proportions of the available stretch allocated to the vertical and horizontal pattern profile. The reduced pattern profile is then orientated on the stretch fabric with the length of the body profile coinciding with the direction of maximum stretch extension.

5.7 THE NEW STRETCH BLOCK DRAFTING RULES

Traditional pattern drafting utilised a pencil and paper, fixed and flexible curves and a rule, which was time consuming. Current technology enables the process to be integrated whereby, once all of the measurements and drafting rules have been computerised, the final pattern draft can be outputted directly onto the paper. For the pattern production process in this study a computer spreadsheet was used to store, manipulate and output the final designs for all pattern pieces.

Pattern drafting, whether manual or computerised, uses vertical and horizontal co-ordinates. Most co-ordinates result from body measurement data, some are algorithms utilising other variables and others can be by rule of thumb. This model applies algorithms to the Form Fit X/Y co-ordinates drafting which will accommodate a range of fabric types that might be required for various levels of fit whilst taking into account basic movement. This algorithm, which is a function of the bias vector, axis ratio and fit factor has been called the reduction factor.

The measurements used in the drafting procedure are taken from Dolly a size 12 full-length dress stand. The stretch block pattern is constructed from direct body measurements to produce a form fit illustrated in Figure 123. The action fit level pattern profile (detailed in the drafting procedure in this section) takes the form fit pattern profile measurements of Dolly which then are reduced applying the reduction factor using the stretch fabric sample B illustrated in Figure 124.

The columns from left to right identify:

- the body measurement number as indicated on the measurement chart in section 5.5.6
- the draft measurement placement and sequence
- the description of the drafting rule
- the X horizontal drafting co-ordinates for the form fit level
- the Y vertical drafting co-ordinates for the form fit level

- the X horizontal drafting co-ordinates for the action fit level fabric B
- the Y vertical drafting co-ordinates for the action fit level fabric B

5.7.1 Drafting Sequence - Lower torso and legs back and front

Body	Draft	Description (Figure 119)	Form Fit		Action Fit	
			X	Y	X	Y
	SW_w	Widest Somato Width **$SW_w = SO_{hip}$**	31.5			
	0	Datum, ankle bone-square across	0.0	0.0	0.0	0.0
46	0-1	Ankle bone to waist up outside leg seam - square across		101.0		93.2
	1-2	**Waist to top hip** - square across		94.5		87.2
31	1-3	Waist to hip - square across		83.0		76.6
68	1-4	Waist to body rise - square across		73.0		67.3
41	1-5	**Waist to thigh** - square across		68.8		63.2
42	1-6	**Waist to above knee** – square across		47.5		43.8
43	1-7	Waist to knee - square across		39.5		36.4
44	1-8	**Waist to calf** - square across		29.0		26.7
45	1-9	Waist to above ankle – square across		5.0		4.6
74	10	Front hip at side **SO_{hip}**	0.0	83.0	0.0	76.6
38	10-11	**Front hip girth / 2**	21.5	83.0	18.1	76.6
72	12	Front waist at side **SO_{waist}**	2.6	101.0	2.2	93.2
32	12-13	**Front waist girth / 2**	18.4	101.0	15.5	93.2
73	14	Front top hip at side **$SO_{top\ hip}$**	1.1	94.5	0.9	87.2
35	14-15	**Front top hip girth / 2**	20.6	94.5	17.3	87.2
75	16	Front fork level at side **SO_{fork}**	0.0	73.0	0.0	67.3
65	16-17	**Front fork point S_{front}**	27.0	73.0	22.7	67.3
74	18	Back hip at side **SO_{hip}**	0.0	83.0	0.0	76.6
39	18-19	**(Back hip girth / 2) – 1**	-23.0	83.0	-19.32	76.6
72	20	Back waist at side **SO_{waist}**	-2.6	101.0	-2.2	93.2
33	20-21	**Back waist girth / 2**	-17.1	101.0	-14.4	93.2

74	22	Back top hip at side $SO_{top\ hip}$	-1.1	94.5	-0.9	87.2
36	22-23	**Back top hip girth / 2**	-20.4	94.5	-17.1	87.2
75	24	Back fork level at side SO_{fork}	0.0	73.0	0.0	67.3
66	24-25	**Back fork point S_{back}**	-29.5	73.0	-24.8	67.3
65	26	Front leg offset = S_{front} / 2	13.5		11.3	
66	27	Back leg offset = S_{back} / 2	14.8		12.4	
47	26-28	**Front thigh girth / 2**	1.0	68.5	0.8	63.2
47	26-29	**Front thigh girth / 2**	26.0	68.5	21.8	63.2
50	26-30	**Above knee girth / 4**	3.8	47.5	3.2	43.8
50	26-31	**Above knee girth / 4**	23.3	47.5	19.7	43.8
51	26-32	Knee girth / 4	5.0	39.5	4.2	36.4
51	26-33	Knee girth / 4	22.0	39.5	18.5	36.4
52	26-34	**Calf girth / 4**	4.8	29.0	4.0	26.7
52	26-35	**Calf girth / 4**	22.3	29.0	18.7	26.7
53	26-36	Above ankle bone girth / 4	7.5	5.0	6.3	4.6
53	26-37	Above ankle bone girth / 4	19.5	5.0	16.4	4.6
54	26-38	Ankle girth / 4	7.6	0.0	6.4	0.0
54	26-39	Ankle girth / 4	19.4	68.5	16.3	63.2
48	27-40	**Back thigh girth / 2**	-29.0	68.5	-24.4	63.2
48	27-41	**Back thigh girth / 2**	-0.5	68.5	-0.4	63.2
50	27-42	**Above knee girth / 4**	-24.7	47.5	-20.7	43.8
50	27-43	**Above knee girth / 4**	-5.0	47.5	-4.2	43.8
51	27-44	Knee girth / 4	-23.3	39.5	-19.6	36.4
51	27-45	Knee girth / 4	-6.3	39.5	-5.3	36.4
52	27-46	**Calf girth / 4**	-23.5	29.0	-19.7	26.7
52	27-47	**Calf girth / 4**	-6.0	29.0	-5.0	26.7
53	27-48	above ankle bone girth / 4	-20.8	5.0	-17.5	4.6

53	27-49	above ankle bone girth /4	-8.8	5.0	-7.4	4.6
54	27-50	Ankle girth / 4	-20.6	0.0	-17.3	0.0
54	27-51	Ankle girth / 4	-8.9	0.0	-7.5	0.0
	19-52	Square down				
	52-53	1.5 cm @ 45º	-24.5	74.0	-20.6	68.1
	11-54	Square down				
	54-55	2.5 cm @ 45º	23.5	75	19.7	69.1

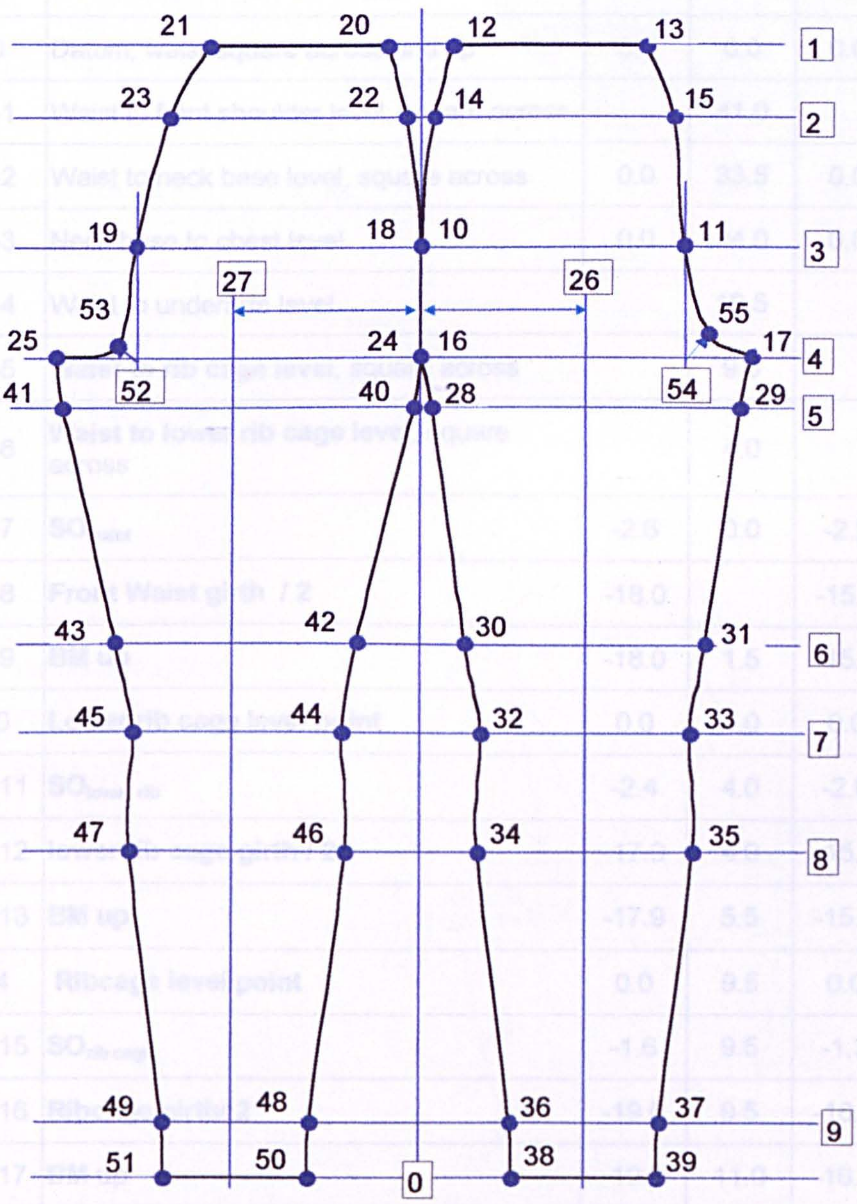


Figure 119 - Drafting Sequence - Back and Front Lower Torso and Legs

5.7.2 Drafting sequence – Front bodice

Body	Draft	Description (Figure 120)	Form Fit		Action Fit	
			X	Y	X	Y
		Bust modifier BM = (B_7-B_8) / 6	1.5	1.5	1.3	1.4
69		**Bust Somato Offset SO_{bust}**	-0.5		-0.4	
70		**Under bust Somato Offset $SO_{under\ bust}$**	-1.6		-1.3	
71		**Lower rib Somato Offset $SO_{lower\ rib}$**	-2.4		-2.0	
72		**Waist Somato Offset SO_{waist}**	-2.6		-2.2	
	0	Datum, waist square across and up	0.0	0.0	0.0	
21	0-1	Waist to front shoulder level, square across		41.0		37.8
17	0-2	Waist to neck base level, square across	0.0	33.5	0.0	30.8
16	0-3	Neck base to chest level	0.0	24.0	0.0	22.1
6	0-4	Waist to underarm level		18.5		17.0
3	0-5	**Waist to rib cage level**, square across		9.5		8.7
4	0-6	**Waist to lower rib cage level**, square across		4.0		3.7
	0-7	**SO_{waist}**	-2.6	0.0	-2.2	0.0
32	7-8	**Front Waist girth / 2**	-18.0		-15.1	
	8-9	**BM up**	-18.0	1.5	-15.1	1.4
	10	**Lower rib cage level point**	0.0	4.0	0.0	3.7
71	10-11	**$SO_{lower\ rib}$**	-2.4	4.0	-2.0	3.7
13	11-12	**lower rib cage girth / 2**	-17.9	4.0	-15.0	3.7
	12-13	**BM up**	-17.9	5.5	-15.0	5.1
	14	**Ribcage level point**	0.0	9.5	0.0	8.7
	14-15	**$SO_{rib\ cage}$**	-1.6	9.5	-1.3	8.7
10	15-16	**Ribcage girth/ 2**	-19.6	9.5	-16.5	8.7
	16-17	**BM up**	-19.6	11.0	-16.5	10.1
	18	**Bust level point**	0.0	18.5	0.0	17.0
	18-19	**SO_{bust}**	-0.5	18.5	-0.4	17.0

7	19-20	**Front bust / 2**	-21.5	18.5	-18.1	17.0
6	20-21	**BM up**	-21.5	20.0	-18.1	18.4
	22	**BM up and right**	-20.0	20.0	-16.8	18.4
	23	Chest level point	0.0	24.0	0.0	22.1
18	23-24	Across chest / 2, square down	-16.0	24.0	-13.4	22.1
	24-25	BM up	-16.0	25.5	-13.4	23.5
17	26	Neck base level point	0.0	33.5	0.0	30.1
24	27	Front shoulder width / 2, square down	-18.3		-15.4	
22	7-28	Arc shoulder angle along 10	-18.3	37.3	-15.4	34.3
25	28-29	Arc shoulder length along 1	-6.8	41.0	-5.7	37.8
	29-30	90º down to neck angle	-4.4	33.5	-3.7	30.8
	30-31	1.5 cm @ 45º neck curve	-3.3	34.6	-2.8	31.8
	32	Underarm intersection	-16.0	20.0	-13.4	18.4
	33	2.5 cm @ 45º underarm curve	-17.9	21.9	-15.0	20.1
	34	FB_{25} = Armscye slope length + 1cm contour allowance (see note)	17.7		17.0	

Note : Armscye slope length (34) to be measured from the pattern draft for both form fit and action fit.

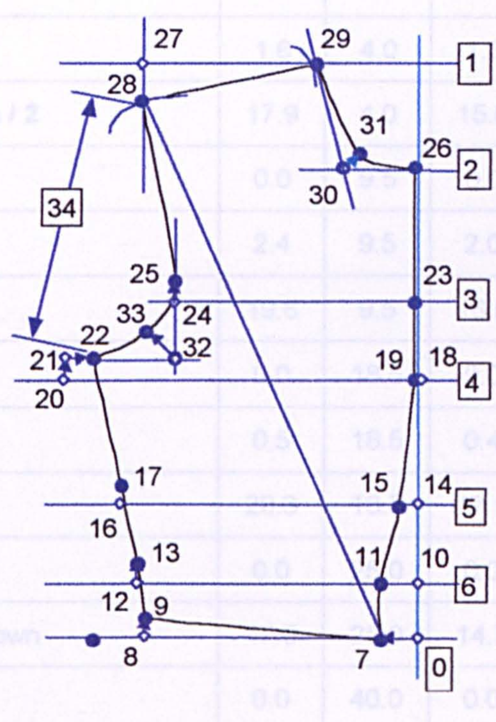
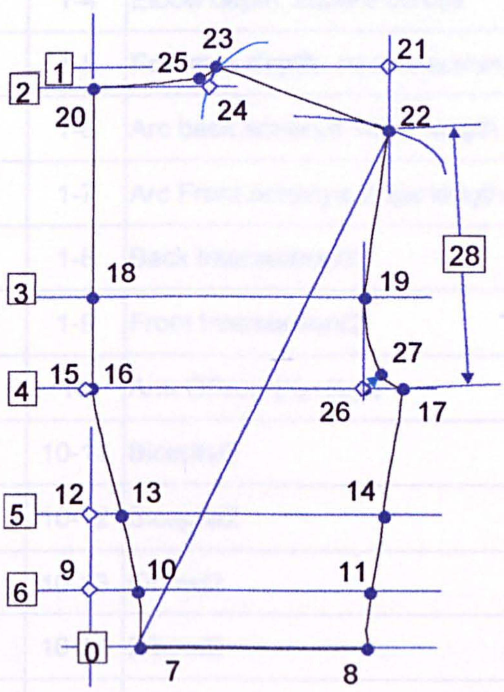


Figure 120 - Drafting Sequence - Front Bodice

5.7.3 Drafting Sequence - Back Bodice

Body	Draft	Description (Figure 121)	Form Fit		Action Fit	
			X	Y	X	Y
69		**Bust Somato Offset SO_{bust}**	0.5		0.4	
70		**Under bust Somato Offset $SO_{under\ bust}$**	1.6		1.3	
71		**Lower rib Somato Offset $SO_{lower\ rib}$**	2.4		2.0	
72		**Waist Somato Offset SO_{waist}**	2.6		2.2	
	0	Datum, square across and up	0.0	0.0	0.0	0.0
28	0-1	Waist to back shoulder level, square across		41.5		38.2
1	0-2	Waist to nape level, square across		40.0		36.8
2	0-3	Nape to mid back level		25.0		23.0
6	0-4	Waist to underarm level		18.5		17.0
3	0-5	**Waist to ribcage level**		9.5		8.7
4	0-6	**Waist to lower ribcage level**		4.0		3.7
73	0-7	**SO_{waist}**	2.6	0.0	2.2	0.0
33	7-8	**Back waist girth / 2**	17.1	0.0	14.4	0.0
	9	**Lower ribcage level point**	0.0	4.0	0.0	3.7
72	9-10	**$SO_{lower\ ribcage}$**	1.6	4.0	1.3	3.7
14	10-11	**Back lower ribcage girth / 2**	17.9	4.0	15.0	3.7
	12	Ribcage level point	0.0	9.5	0.0	8.7
71	12-13	**$SO_{ribcage}$**	2.4	9.5	2.0	8.7
11	13-14	**Back ribcage girth / 2**	19.6	9.5	16.5	8.7
	15	Bust level point	0.0	18.5	0.0	17.0
70	15-16	**SO_{bust}**	0.5	18.5	0.4	17.0
8	16-17	**Back bust girth /2**	20.3	18.5	17.1	17.0
	18	Mid back level point	0.0	25.0	0.0	23.0
26	18-19	Across back / 2, square down	17.5	25.0	14.7	23.0
	20	Nape level point	0.0	40.0	0.0	36.8
27	21	Back shoulder width / 2, square down	19.0		16.0	

	7-22	Arc shoulder slope along 21	19.0	35.2	16.0	32.4
	22-23	Arc shoulder length along 1	8.8	41.5	7.4	38.2
	23-24	90º down to neck angle	8.0	40.0	6.7	36.8
	24-25	0.5 cm @ 45º neck curve	7.5	40.5	6.3	37.3
	26	Underarm intersection	17.5	18.5	14.7	17.0
	26-27	1.5 cm @ 45º underarm curve	18.6	19.6	15.9	18.0
	28	BB_{23} = Armscye slope length + 1cm contour allowance (see note)	16.9		15.4	



Note : Armscye slope length (28) to be measured from the draft pattern for both form fit and action fit.

Figure 121 - Drafting Sequence - Back Bodice

5.7.4 Drafting Sequence – Sleeve

Body	Draft	Description (Figure 122)	Form Fit		Action Fit	
			X	Y	X	Y
	X_{axis}	Datum		0.0		0.0
		Arm crown angle $Ø_{crown}$	45°			
59	0-1	Arm length level outer, square across		58.5		53.8
55	1-2	**Sleeve head depth**, square across		51.0		47.0
56	1-3	Bicepdepth, square across		37.5		34.5
57	1-4	Elbow depth, square across		27.0		24.8
58	1-5	**Forearm depth**, square across		16.5		15.2
	1-6	Arc back armscye slope length (see note)	-16.9	51.0	-15.4	47.0
	1-7	Arc Front armscye slope length (see note)	17.7	51.0	17.0	47.0
60	1-8	Back Intersection/2	-8.8	54.6	-7.4	50.2
60	1-9	Front Intersection/2	8.8	54.8	7.4	50.4
	10	Arm Offset=$(X_6+X_7)/2$	0.4		0.3	
62	10-11	Bicepts/2	-12.8	37.5	-10.8	34.5
62	10-12	Bicepts/2	13.7	37.5	11.5	34.5
63	10-13	Elbow/2	-12.1	27.0	-10.2	24.8
63	10-14	Elbow/2	12.9	27.0	10.8	24.8
64	10-15	**Forearm/2**	-10.6	16.5	-8.9	15.2
64	10-16	**Forearm/2**	11.4	16.5	9.6	15.2
65	10-17	Wrist/2	-7.6	0.0	-6.4	0.0
65	10-18	Wrist/2	8.4	0.0	7.1	0.0

Note : The co-ordinates 1-6 and 1-7 correspond to the armscye slope measurement co-ordinates 28 on the back and 34 on the front bodice Pattern

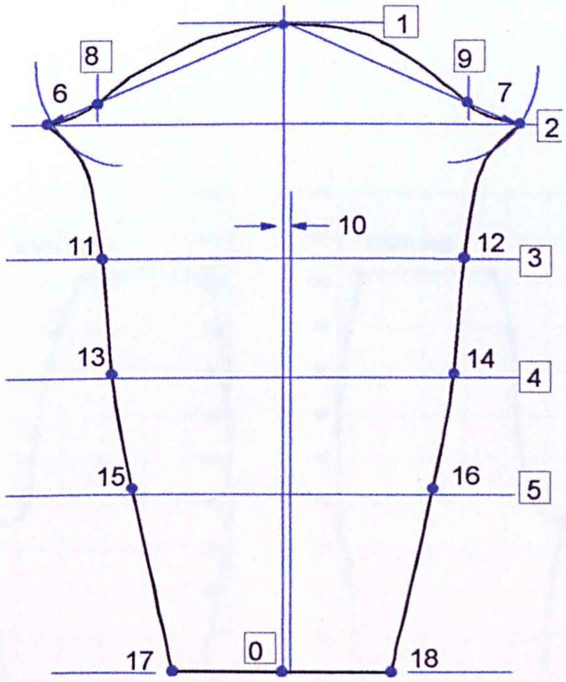
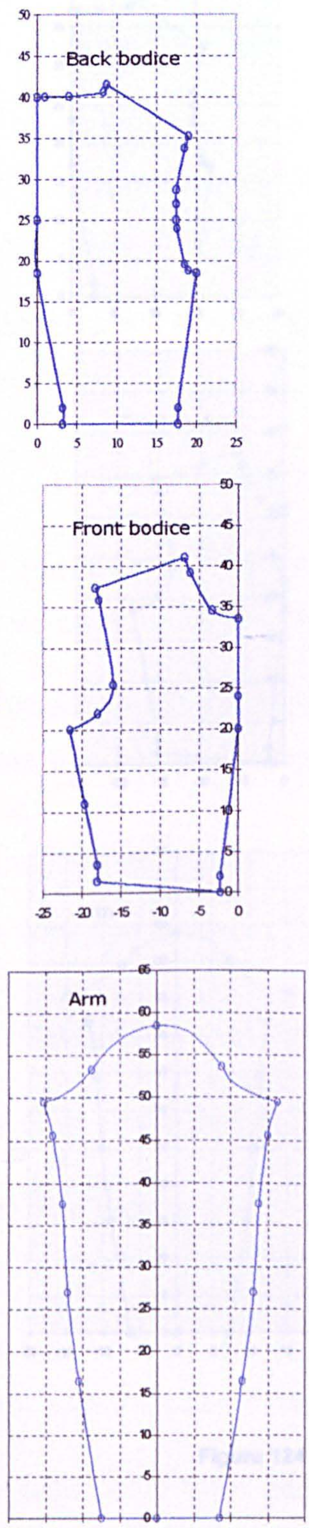


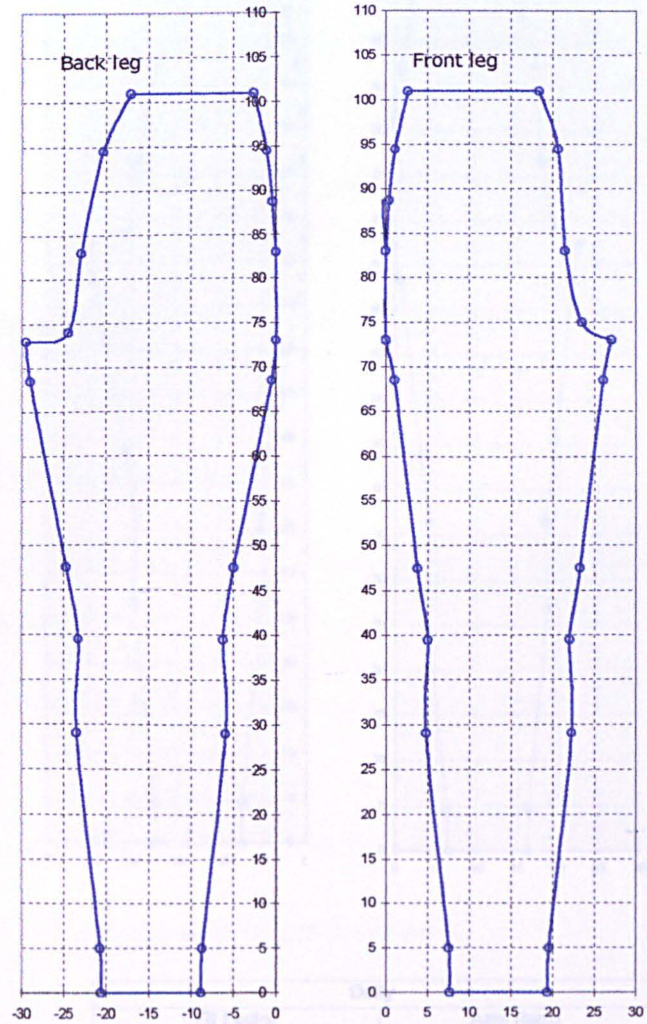
Figure 122 - Drafting Sequence - Sleeve

The drafting sequences shown in Figures 119, 120, 121 and 122 construct a stretch block pattern that closely contours the body at form fit level. A completed form fit pattern draft for Dolly is illustrated in Figure 123. After the co-ordinates for form fit pattern have been established they can then be reduced according to the fit level requirement and the chosen stretch fabric. A stretch block pattern draft reduced to an action fit level for Dolly using fabric B is illustrated in Figure 124. The pattern profile geometry of the new stretch block Figures 123 and 124 can be compared with existing stretch patterns illustrated in sections 3.10.5, 3.10.7 and 3.10.8. Significant differences are apparent in the sleeve crown and armhole area and around the crutch where the contour of the pattern profile has not been rationalised to straighten or make the curves more fluid. A comparison between the new stretch block draft and traditional pattern drafting approaches is discussed in section 5.8.

5.7.5 Stretch Block Pattern Draft - Form Fit

(see Figure 123)



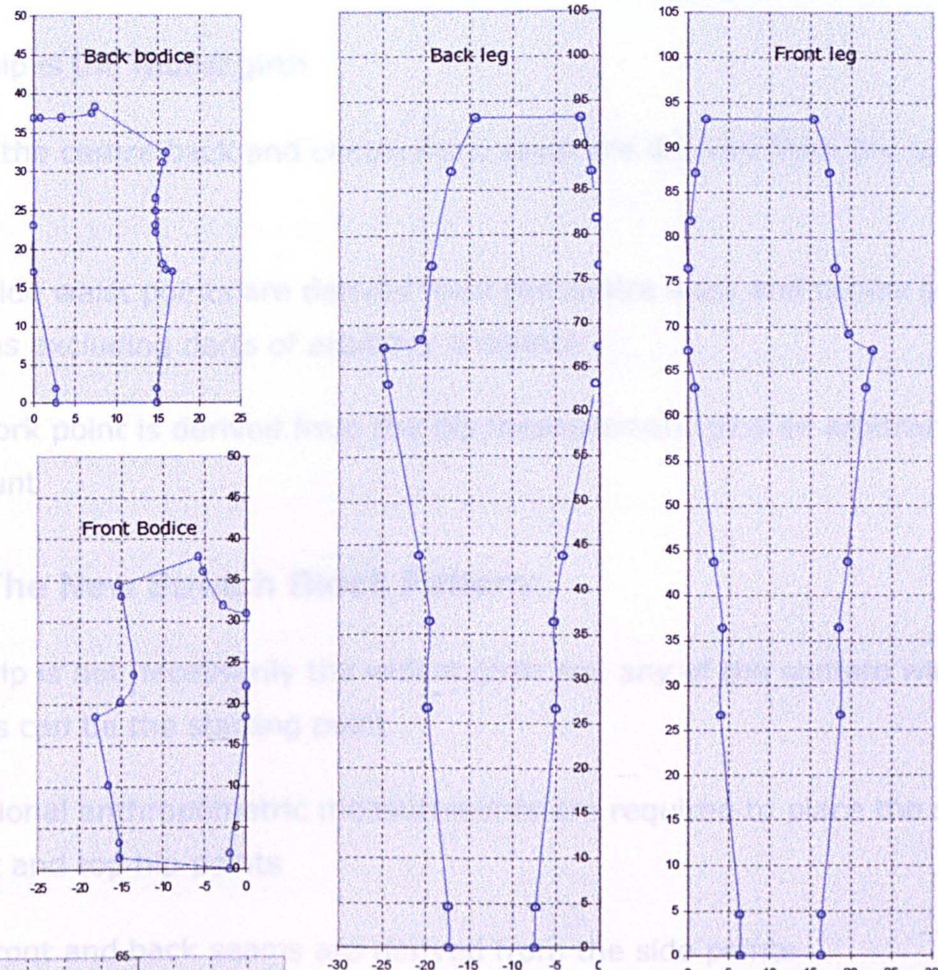


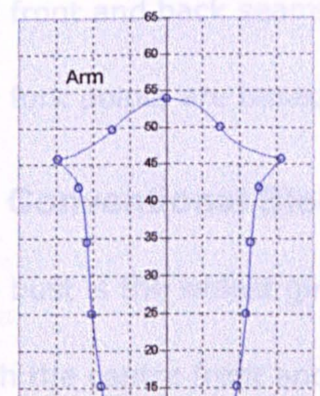
Dolly			
Fit Factor		**Axis Ratio**	
Form	0.00	**Course**	2
		Wale	7
Fabric			
Sample	C		
Quality	21132		
Desc	32gg 260g Animalmax		
Polyester	88		
Elastane	12		
Colour	White NR4888		
Hanger Load		**Reduction Factor**	
Course	56	**Course**	1.00
Wale	20	**Wale**	1.00
Bias	45		

Figure 123- Dolly, Sample C, Form Fit Pattern Profile

5.7.6 Stretch Block Pattern Draft – Action Fit

(see Figure 124)





Dolly			
	Fit Factor	Axis Ratio	
Action	0.75	Course	2
		Wale	7
Fabric			
Sample	B		
Quality	21132		
Desc	32gg 260g Animalmax		
Polyester	88		
Elastane	12		
Colour	White SDI10014		
Hanger Load		Reduction Factor	
Course	56	Course	0.92
Wale	20	Wale	0.84
Bias	45		

Figure 124 - Dolly, Sample B, Action Fit Pattern Profile

5.8 COMPARISON BETWEEN CONVENTIONAL AND THE NEW STRETCH BLOCK PATTERN DRAFT FEATURES

5.8.1 Conventional Block Trouser Pattern Design:

- the hip is the widest girth
- both the centre back and centre front seam are derived from the side hip point
- the side waist points are derived from the centre front and centre back *seams excluding darts of arbitrary amounts*
- the fork point is derived from the hip measurement plus an arbitrary amount

5.8.2 The New Stretch Block Pattern:

- the hip is not necessarily the widest girth and any of the somato width levels can be the starting point
- additional anthropometric measurements are required to place the side waist and top hip points
- the front and back seams are derived from the side points
- the fork points are based on direct body measurements.

5.8.3 Conventional Block Bodice Pattern:

- the bust is the widest girth
- both the centre front and centre back points are derived from the bust width which is divided equally between them
- the side waist is derived from the centre front point and centre back point and includes darts of arbitrary amounts
- the side seam from waist level to bust level includes darts which are derived from arbitrary amounts

- the shoulder angle including darts is derived through an arbitrary measurement.

5.8.4 The New Stretch Block Pattern:

- the bust is the widest girth
- the width of the bodice front and back is based on measurements taken
- additional anthropometric measurements are required to place the side seam at front and back
- the side waist and centre front point and centre back point is based on the somato offset
- additional anthropometric measurements are required to place the side seams from waist to bust level
- the shoulder angle is determined by an arc measurement from the waist at the centre front point.

5.8.5 Conventional Sleeve Block Pattern:

- the widest girth is the upper arm
- the crown depth is an arbitrary amount
- the sleeve is divided in line with the shoulder point equally between the front and back sleeve.

5.8.6 The New Stretch Block Pattern:

- the widest girth is the upper arm
- the crown depth is a measurement between the shoulder point at the top of the crown to the intersection between the arm and chest
- the front and back sleeve apportionment is determined by the measurement of the shoulder seam around the armscye front and the shoulder seam armscye back.

5.9 BODYSUIT ANALYSIS AND EVALUATION

A stretch knit performancewear garment should display no wrinkles have minimal stretch distortion and conform to the body contours to facilitate a range of movement, without displacing or straining the fabric.

Stretch garment assessment is interpretive; the quality of the body contouring fit is inextricably linked with the stretch potential of fabric characteristics. Defining the fit quality expectations and the fit level category is paramount in the assessment of the garment-to-body contouring fit relationship. To focus the garment analysis and evaluation in the stretch block pattern development process a fitting scheme was implemented. The stretch fabric characteristics were made visible by printing a 2.5cm grid on the stretch fabric before the bodysuit toile was constructed. A key was used to identify the observable stretch deformation in the grid pattern on the analysis garment. Observation of the squares highlighted the direction of stretch relative to the pattern straight grain line and the amount of stretch distortion at each square. The toile was assessed overall for wrinkle and stretch deformation. A wrinkle is indicative of any fabric stretch to body disparity and the grid deformation highlights the direction and magnitude of localised stretch. In a form fit toile the unavoidable but acceptable stretch has been referred to as Tare Stretch.

5.9.1 Static Assessment

The stretch block pattern starting point of the form fit garment was based on Dolly (the dress stand) which, was used as a static visual reference only, therefore, certain limitations on the pattern production process imposed by Dolly needed defining.

5.9.1.1 Limbs

The limbs in general were not a true representation of the human form.

The joints between the limbs and the torso were not defined with suitable change in contour.

Because the limbs were rigid, no stretch and recovery actions could be performed.

5.9.1.2 Flesh

Canvas does not have the properties of human skin and because it has a *high frictional resistance fabric stays were placed as opposed to reaching a* state of equilibrium at rest.

Because of Dolly's rigidity and non-representative canvas covering, the fabric behaviour around protrusions such as the bust and buttock on a human could not be recreated.

5.9.1.3 Contours

The form persuasive hugging power of fabric could not be recreated over Dolly's contours also the fabric could not retract between the buttocks, as they were not defined.

5.9.2 Dynamic Assessment

To gain a more realistic analysis and evaluation of the stretch block pattern theories the garments were assessed dynamically on three subjects (Fiona, Michael and Natasha). To highlight any fit disparities a series of movements, which fully flexed the body and the fabric, were performed.

5.9.3 Stretch Block Form Fit Commentary

5.9.3.1 General

- Dolly: The impositions of Dolly's non-representative body form were anticipated but the junction with the torso and the shape of the upper arms was particularly challenging. There was little point in trying to accommodate the limitations imposed on the quality of the garment fit in this area but to trust that the ideation behind the dynamic crown angle would be validated in the human assessment. In general the overall fit is good, however, the inadequacies of the fit of the upper arm can be clearly seen in the form fit photographs of Dolly (see Dolly form fit evaluation chart Table 20 and area photographs Figures 125 and 126 and Appendix E).

- Michael: A typical young man, not yet fully developed, made contouring the upper arms in an acceptable fit challenging but achievable, otherwise the overall fit was good (see Michael form fit evaluation chart and area photographs in Appendix F).

- Fiona: An athletic young woman, a good result was achieved (see Fiona form fit evaluation chart and area photographs in Appendix G).

- Natasha: Generally not a good form fit because she lost a considerable amount of weight between measurement and assessment (see Natasha form fit evaluation chart and area photographs in Appendix H).

5.9.3.2 Wrinkles

- Dolly: The results were predictable with minimal wrinkles but with the most appearing around the armscye exacerbated by the unrealistic body form.

- Michael: Wrinkles mainly around the upper arm with slight looseness towards the extremities.

- Fiona: Wrinkles under the upper arm towards the armpit and slight looseness towards the extremities.

- Natasha: The areas of wrinkles were a result of the garment finding its own equilibrium, consistent with the garment being too loose.

5.9.3.3 Tare stretch

- Dolly: Her constancy was used to good effect to establish minimum unavoidable but acceptable stretch to accommodate the undulations of the body.

- Michael, Fiona and Natasha's pattern geometry accommodated minimal tare stretch with a good cross sectional representation.

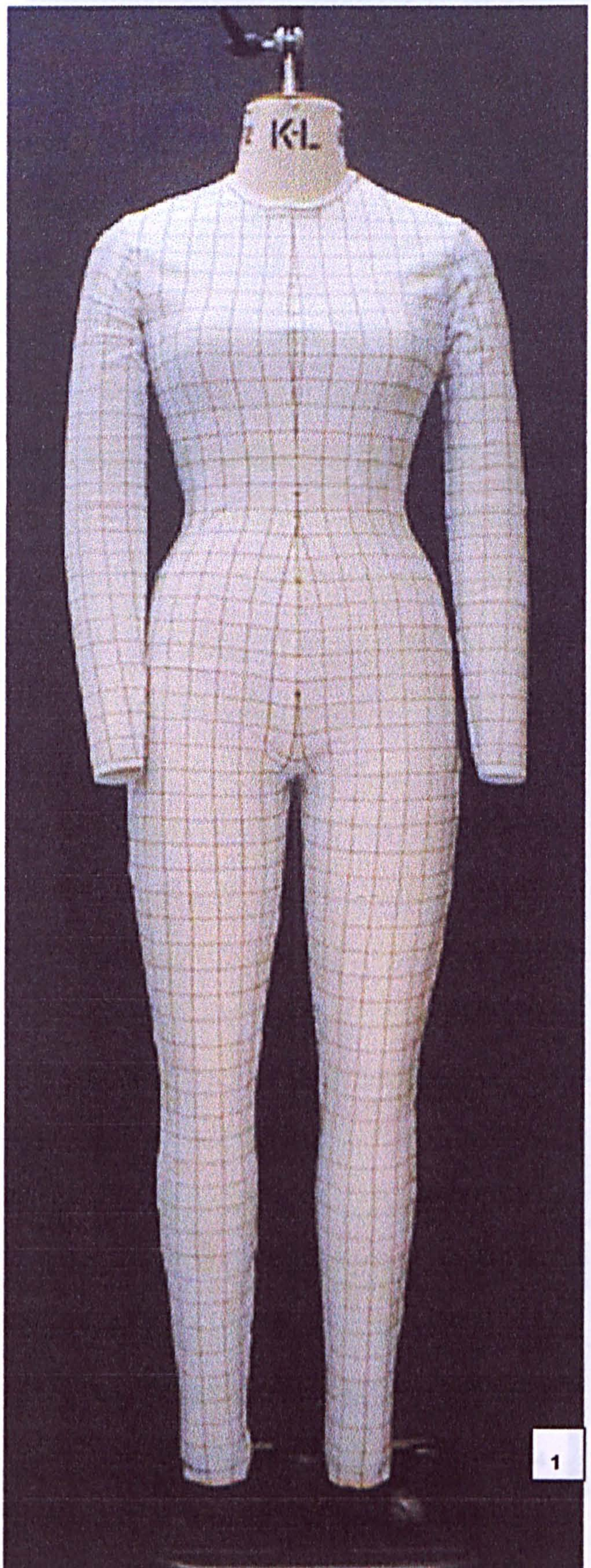
5.9.3.5 Stretch

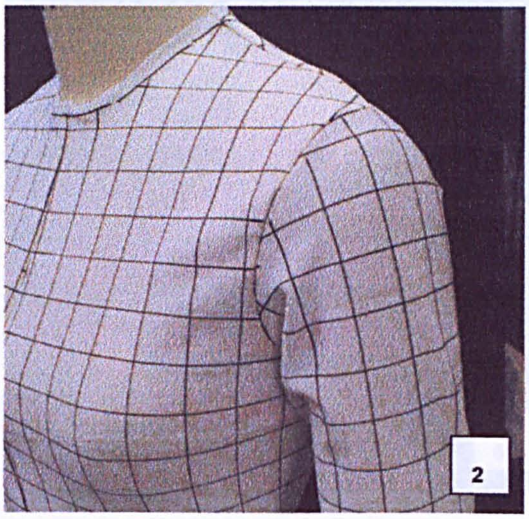
- Stretch was not relevant in the assessment of the form fit toile.

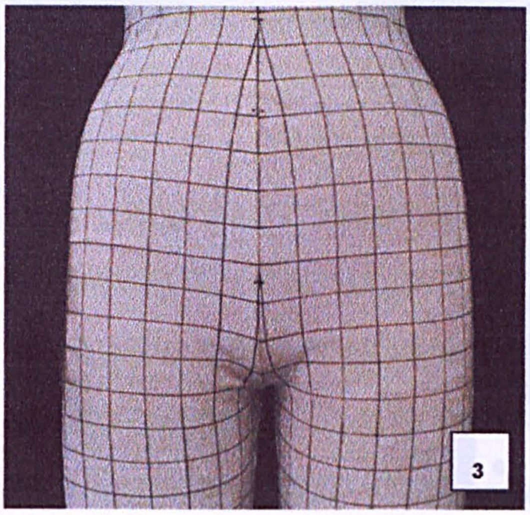
5.9.3.5 Dolly, Form Fit Bodysuit Fabric Sample C Evaluation Chart and Area Photographs

Name: Dolly		**Garment:** Form Fit		
Area	**General**	**Wrinkle**	**Tare stretch**	**Stretch**
1-Front	Good	Minimal	Minimal	N.A.
2-Front armscye and chest	Good	Unavoidable around armscye	Predicted chest trapezoids	N.A.
3-Bodyrise and top thigh	Good	Minimal	Minimal	N.A.
4-Back	Good	Minimal	Minimal	N.A.
5-Shoulder and crown	Good	None	None	N.A.
6-Back armscye and shoulder blade	Good	Unavoidable around armscye	Rhomboid under shoulder blade	N.A.
7-Seat and top thigh	Good	None	Minimally enlarged squares and trapezoids	N.A.
Comments: Unable to manipulate the dress stand into the defined position. The arm shape and positioning is particularly unrealistic. Overall fit very good.				

Table 20 - Dolly, Form Fit Bodysuit Fabric Sample C Evaluation Chart







DOLLY			
Fit Factor		**Axis Ratio**	
Form	0.00	**Course**	2
		Wale	7
Fabric			
Sample	C		
Quality	21132		
Desc	32gg 260g Animalmax		
Polyester	88		
Elastane	12		
Colour	White NR4888		
Hanger Load		**Reduction Factor**	
Course	52	**Course**	1.00
Wale	32	**Wale**	1.00
Bias	53		

Figure 125 - Dolly Form Fit Bodysuit Front View

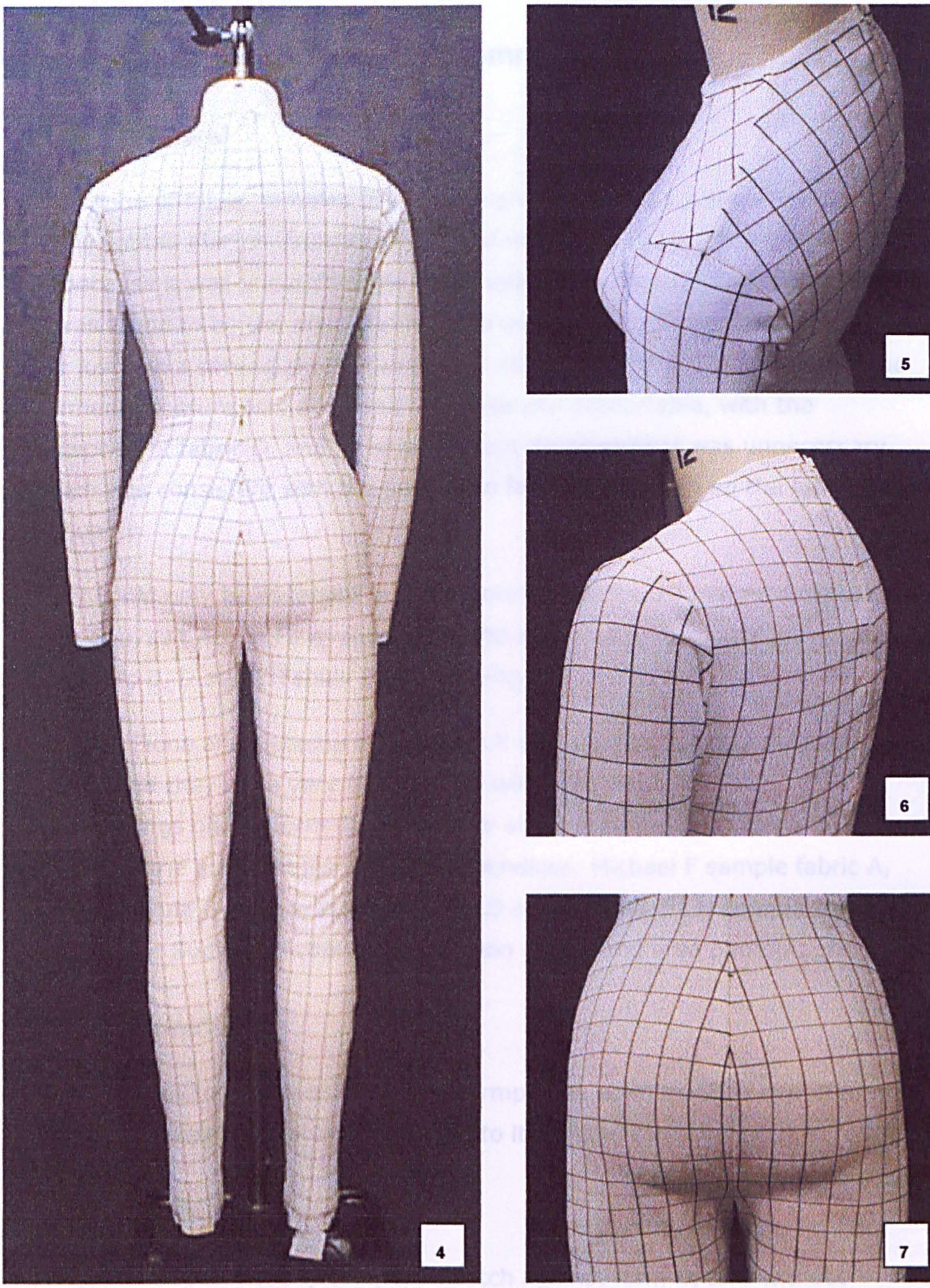


Figure 126– Form Fit Back View

5.9.4 Stretch Block Action Fit Commentary

5.9.4.1 General

The range of fabric samples helped to highlight problem areas. Fabric D had a limited stretch capacity and would not normally be chosen for action fit because it was uncomfortable which inhibited freedom of mobility. Fabric B was found to be the most comfortable and flexible; Michael stated that "it felt just like a second skin". Comments about all fabrics used were that the garment pressure was even and felt generally comfortable, with the exception of fabric D, and after movement readjustment was unnecessary which was consistent with the pattern to fabric orientation on the fabric and fit quality.

Dolly could only be assessed in visual terms, which were overall satisfactory (see Bodysuit Action Fit evaluation charts and area photographs for sample fabrics A, B, D and E Tables 21-14 and Figures 127-134 in Appendix E).

Michael, Fiona and Natasha enabled a full assessment because they were mobile and they were very forthcoming with their feedback! Any shortcomings on the form fit were easily accommodated by the fabric stretch at the action fit level. (See Appendices: Michael F sample fabric A, Band D; Fiona G sample fabric A, B, C, D and E; Natasha H sample fabric A, Band D; for Bodysuit Action Fit evaluation charts and area photographs.)

5.9.4.2 Wrinkles

Minimal wrinkling occurred under the armpit but no more than expected. Fabric D proved to be problematic due to its limited stretch factor.

5.9.4.3 Tare

It was difficult to visually compare stretch against form fit tare without using very laborious mathematical analysis, but the compressive properties of fatty tissue in areas of protrusion were accommodated by the stretch fit level.

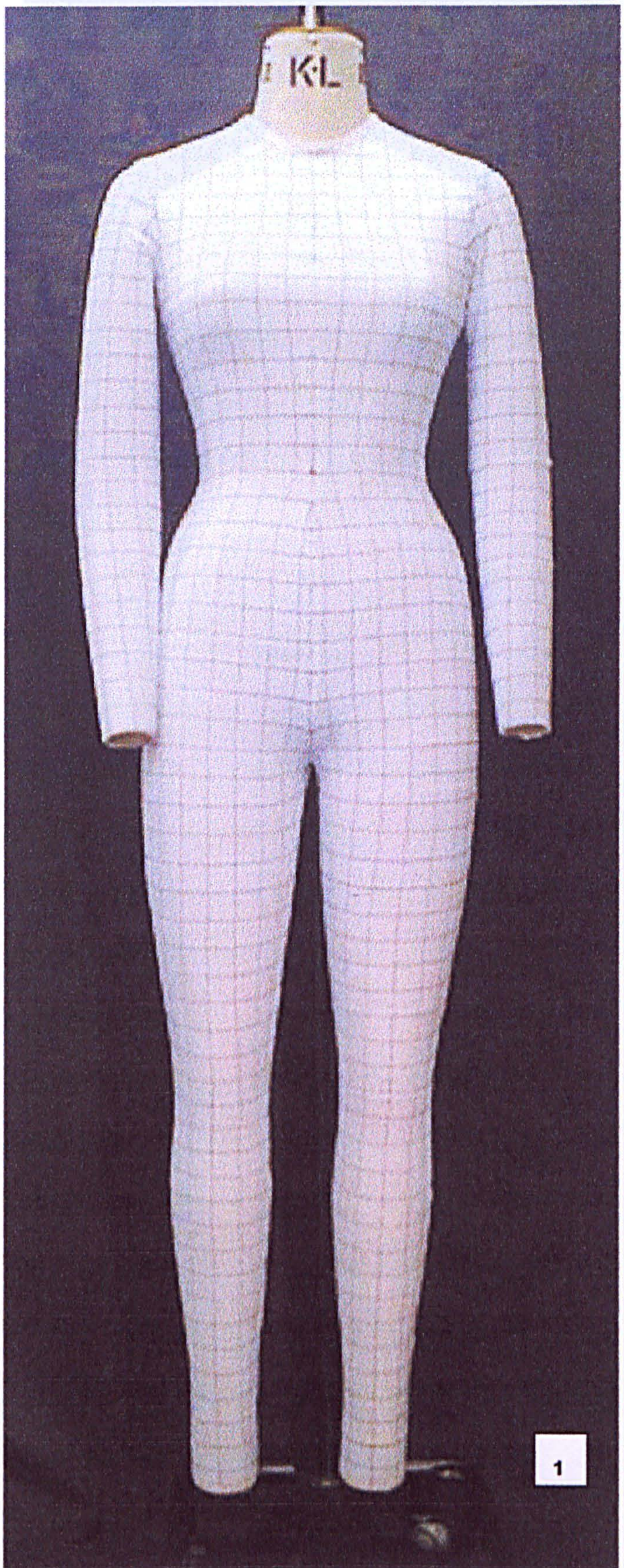
5.9.4.4 Stretch

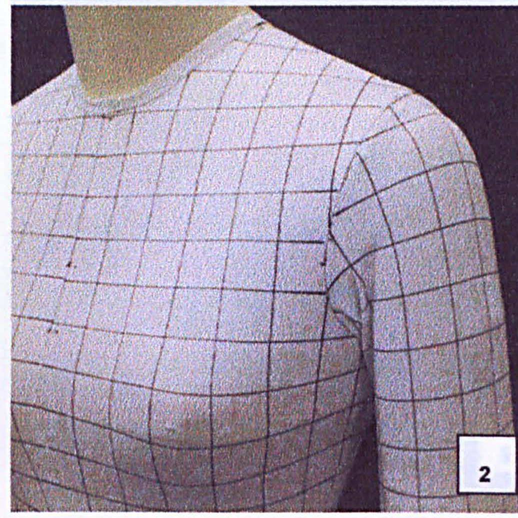
With the exception of fabric D with its low stretch factor, the 7:2 axis ratio and pattern orientation retained the fabric stretch in the low modulus working range, which allowed for mobility in the other fabrics without displacing the assessment toile. The higher bias component in Fabric B afforded additional stretch in the wale direction, and this could account for the additional comfort experienced here.

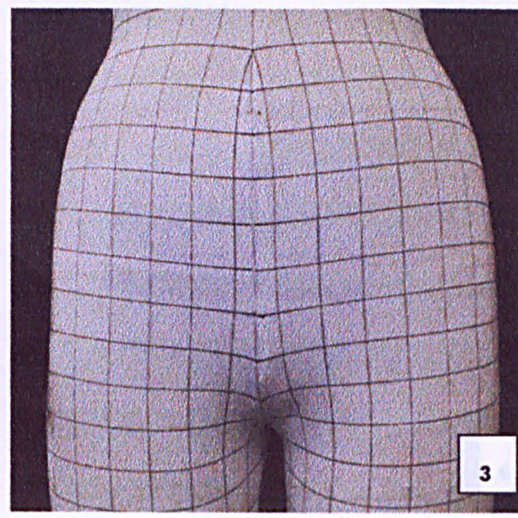
5.9.4.5 Dolly, Action Fit Bodysuit Fabric Sample A Evaluation Chart and Area Photographs

Name: Dolly		**Garment:** Sample A		
Area	**General**	**Wrinkle**	**Tare stretch**	**Stretch**
1-Front	Very good	None	Minimal	Rectangular
2-Front armscye and chest	Very good	Unavoidable but minimal	Predictable chest trapezoids	Rectangular chest trapezoids
3-Bodyrise and top thigh	Very good	None	Rectangular	Rectangular with rhomboids orientating towards fork level
4-Back	Very good	None	Minimal	Rectangular
5-Shoulder and crown	Very good	None	Rectangular, square at crown	Enlarged squares
6-Back armscye and shoulder blade	Very good	Unavoidable but minimal	Slight trapezoid under shoulder blade	Rectangular with rhomboids orientated towards under arm
7-Seat and top thigh	Very good	none	Minimally enlarged squares and trapezoids	Rectangles on top hip, seat enlarged squares, rhomboids at under seat and top thigh orientated towards seat cleavage
Comments: Unable to manipulate the dress stand into the defined position. The arm shape and positioning is particularly unrealistic. Overall fit very good.				

Table 21- Dolly, Action Fit Bodysuit Fabric Sample A Evaluation Chart







DOLLY			
Fit Factor		**Axis Ratio**	
Action	.75	**Course**	2
		Wale	7
Fabric			
Sample	A		
Quality	**21649**		
Desc	**32gg 210g Coolmax/Lycra**		
Polyester	**84**		
Elastane	**16**		
Colour	**White NR5079**		
Hanger Load		**Reduction Factor**	
Course	36	**Course**	0.94
Wale	28	**Wale**	0.83
Bias	40		

Figure 127- Dolly Action Fit Bodysuit Fabric Sample A Front View

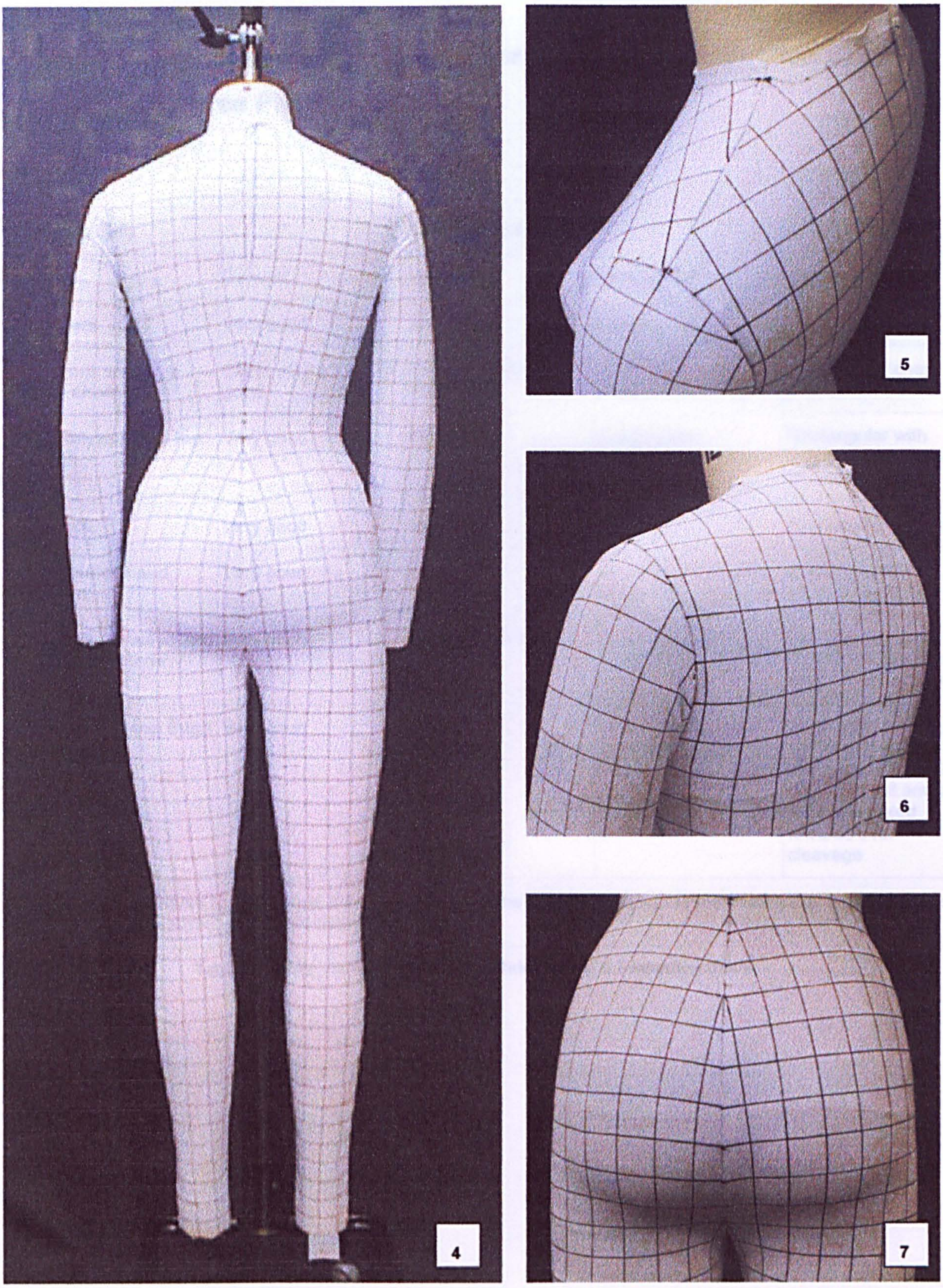
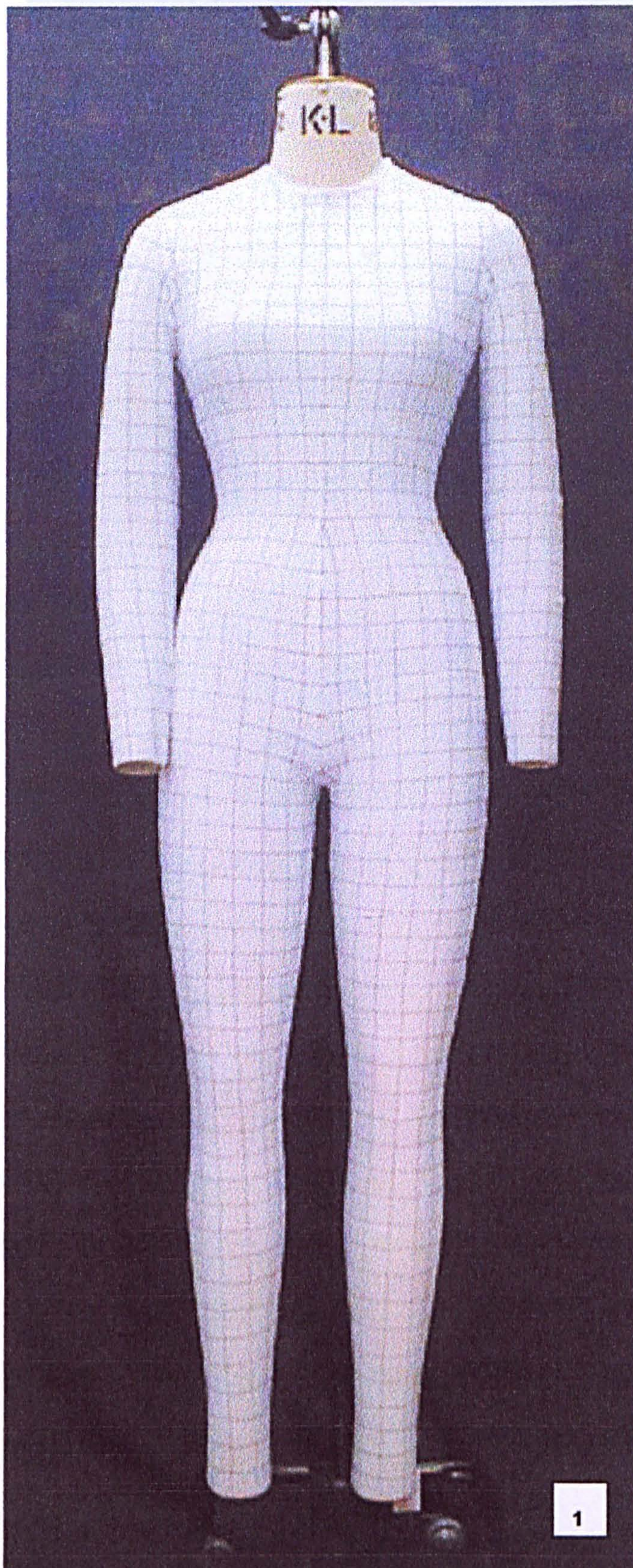


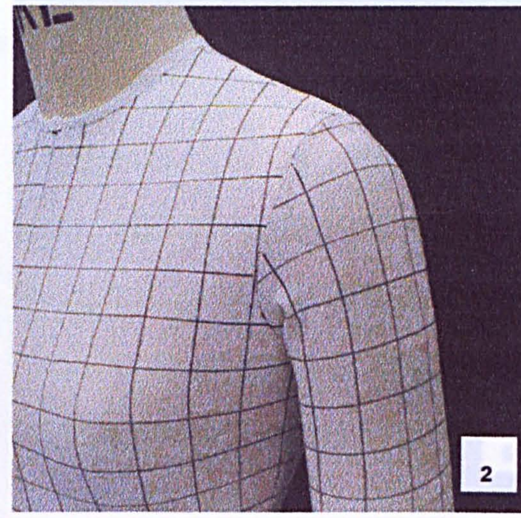
Figure 128- Dolly Action Fit Bodysuit Fabric Sample A Back View

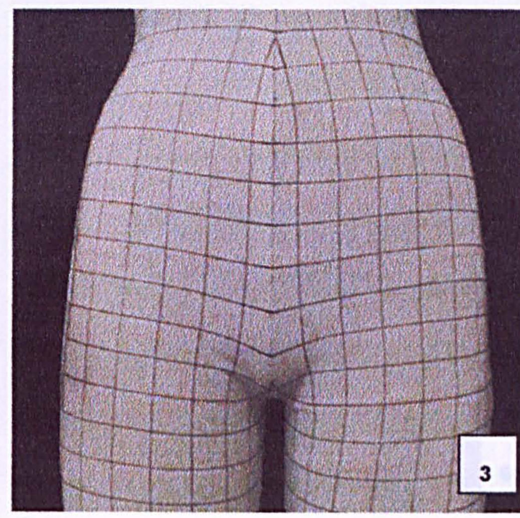
5.9.4.6 Dolly, Action Fit Bodysuit Fabric Sample B Evaluation Chart and Area Photographs

Name: Dolly		**Garment**: Sample B		
Area	General	Wrinkle	Tare stretch	Stretch
1-Front	Very good	None	Minimal	Rectangular
2-Front armscye and chest	Chest very good, arm good	Unavoidable but minimal	Predictable chest trapezoids	Rectangular chest trapezoids
3-Bodyrise and top thigh	Very good	None	Rectangular	Rectangular with rhomboids orientating towards fork level
4-Back	Very good	None	Minimal	Rectangular
5-Shoulder and crown	Very good	None	Rectangular, square at crown	Enlarged squares
6-Back armscye and shoulder blade	Very good	Unavoidable but minimal	Slight trapezoid under shoulder blade	Rectangular with rhomboids orientated towards under arm
7-Seat and top thigh	Very good	none	Minimally enlarged squares and trapezoids	Rectangles on top hip, seat enlarged squares, rhomboids at under seat and top thigh orientated towards seat cleavage
Comments: Unable to manipulate the dress stand into the defined position. The arm shape and positioning is particularly unrealistic. Overall fit very good				

Table 22 - Dolly, Action Fit Bodysuit Fabric Sample B Evaluation Chart







DOLLY			
Fit Factor		**Axis Ratio**	
Action	.75	**Course**	2
		Wale	7
Fabric			
Sample	B		
Quality	21132		
Desc	32gg 260g Animalmax		
Polyester	88		
Elastane	12		
Colour	White SDI10014		
Hanger	**Load**	**Reduction Factor**	
Course	56	**Course**	0.92
Wale	20	**Wale**	0.84
Bias	45		

Figure 129 Dolly Action Fit Bodysuit Fabric Sample B Front View

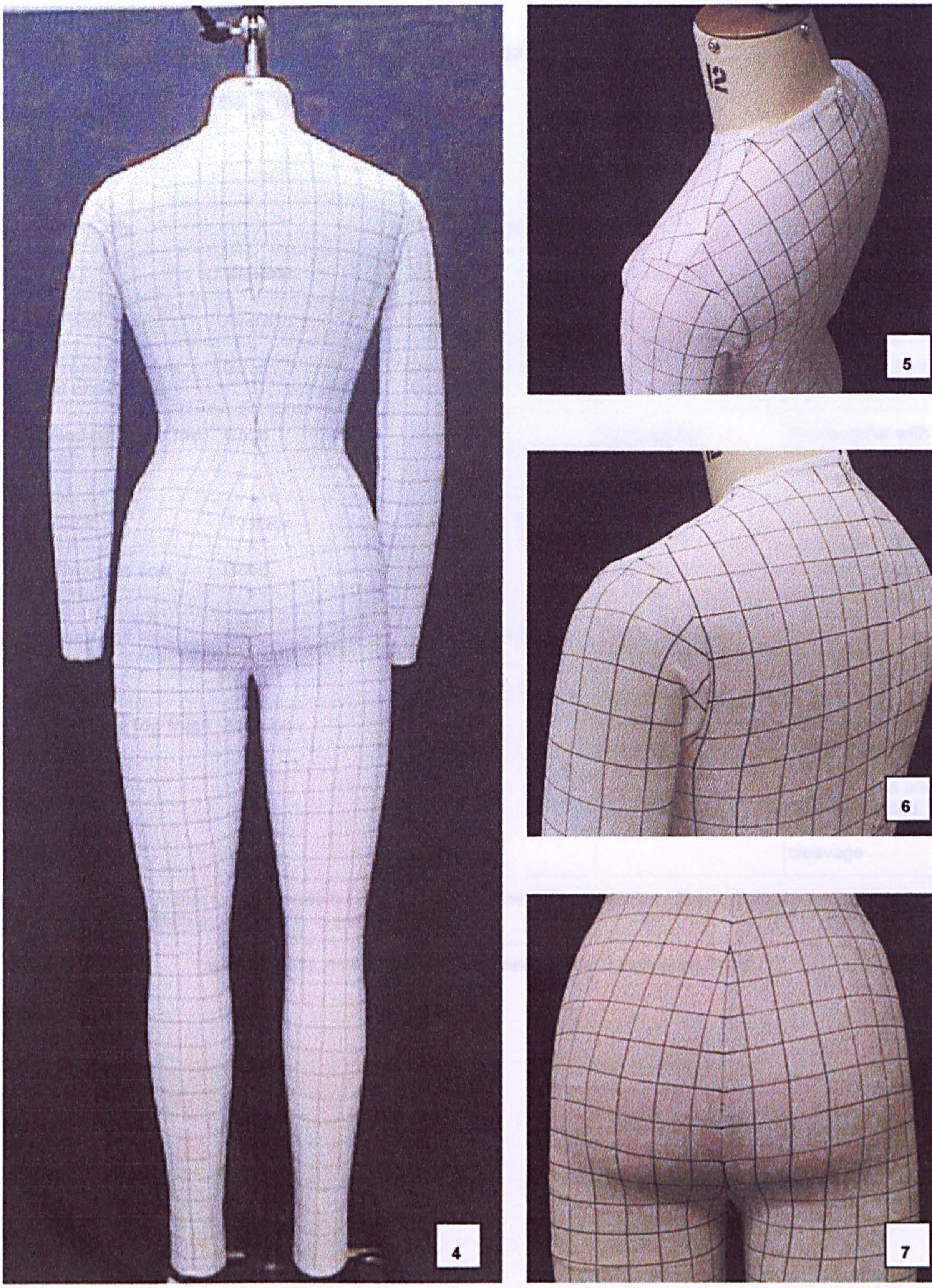
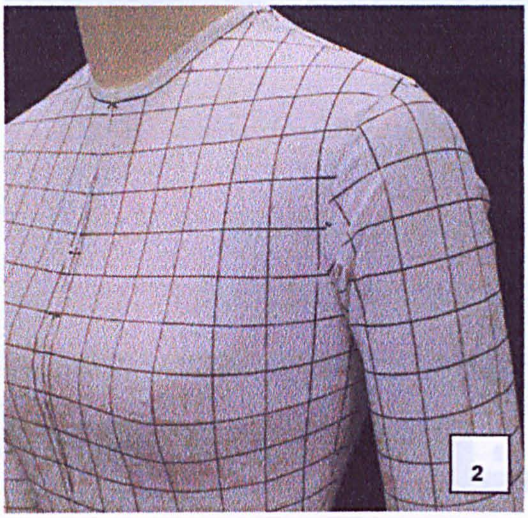


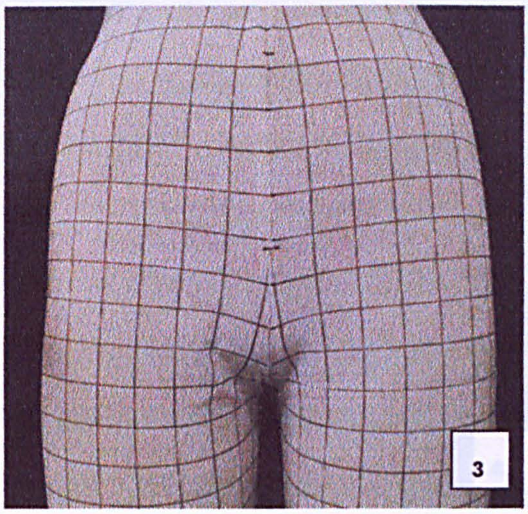
Figure 130- Dolly Action Fit Bodysuit Fabric Sample B Back View

5.9.4.7 Dolly, Action Fit Bodysuit Fabric Sample D Evaluation Chart and Area Photographs

Name Dolly		**Garment**: Sample D		
Area	**General**	**Wrinkle**	**Tare stretch**	**Stretch**
1-Front	Average	Predictable	Minimal	Rectangular
2-Front armscye and chest	Good	Unavoidable but predictable	Predictable chest trapezoids	Rectangular chest trapezoids
3-Bodyrise and top thigh	Good	minimal	Rectangular	Rectangular with rhomboids orientating towards fork level
4-Back	Average	Predictable	Minimal	Rectangular
5-Shoulder and crown	Good	None	Rectangular, square at crown	Enlarged squares
6-Back and shoulder blade	Good	Unavoidable but predictable	Slight trapezoid under shoulder blade	Rectangular with rhomboids orientated towards under arm
7-Seat and top thigh	Average	minimal	Minimally enlarged squares and trapezoids	Rectangles on top hip, seat enlarged squares, rhomboids at under seat and top thigh orientated towards seat cleavage
Comments: Unable to manipulate the dress stand into the defined position. The arm shape and positioning is particularly unrealistic. Overall fit is good.				

Table 23 - Dolly, Action Fit Bodysuit Fabric Sample D Evaluation Chart





DOLLY			
Fit Factor		**Axis Ratio**	
Action	.75	**Course**	2
		Wale	7
Fabric			
Sample	D		
Quality	22203		
Desc	56gg 220g Coomax/T902 Triskin		
Polyester	80		
Elastane	20		
Colour	White SDI 10515		
Hanger Load		**Reduction Factor**	
Course	18	**Course**	0.97
Wale	10	**Wale**	0.93
Bias	15		

Figure 131 -Dolly Action Fit Bodysuit Fabric Sample D Front View

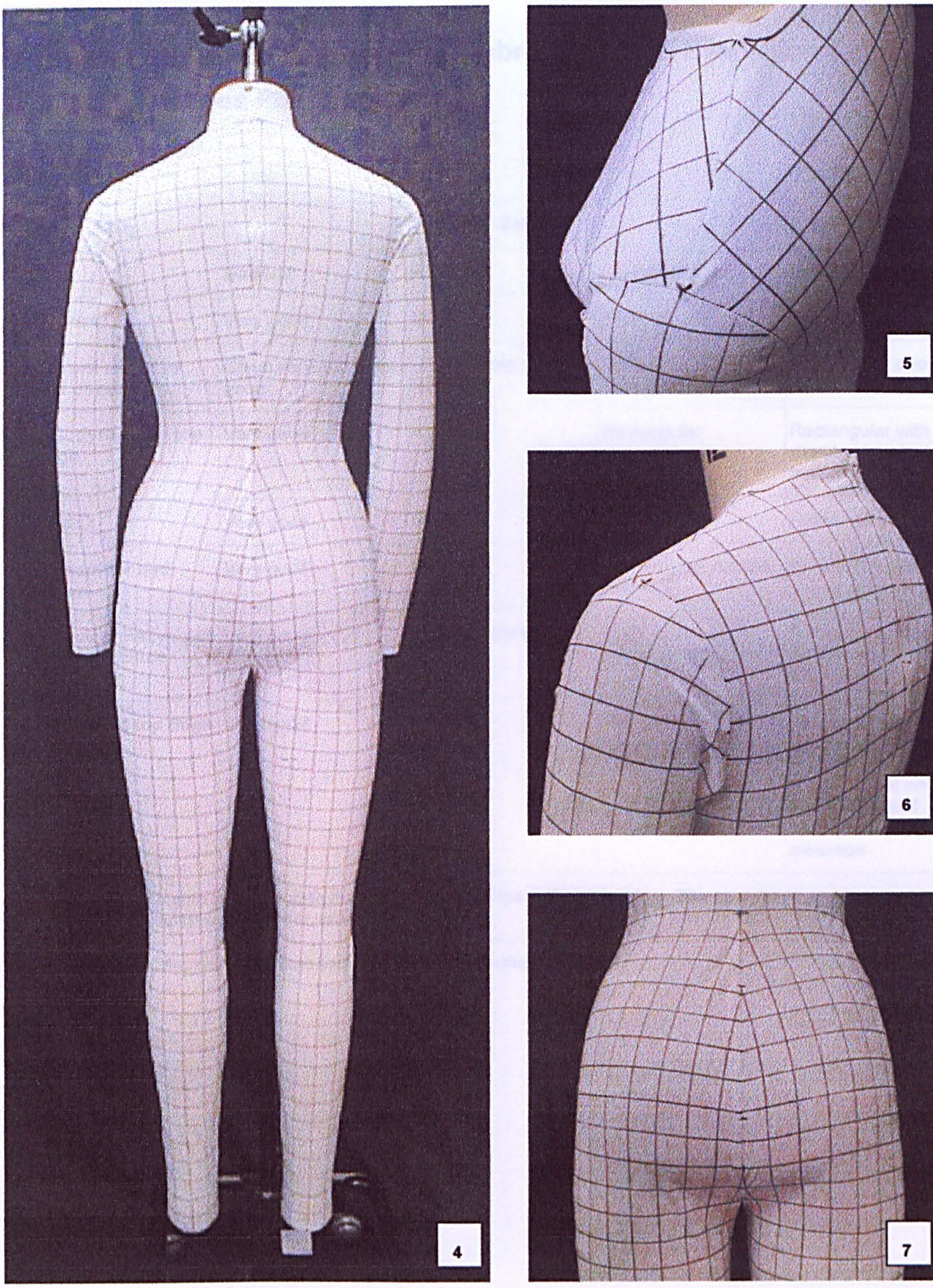
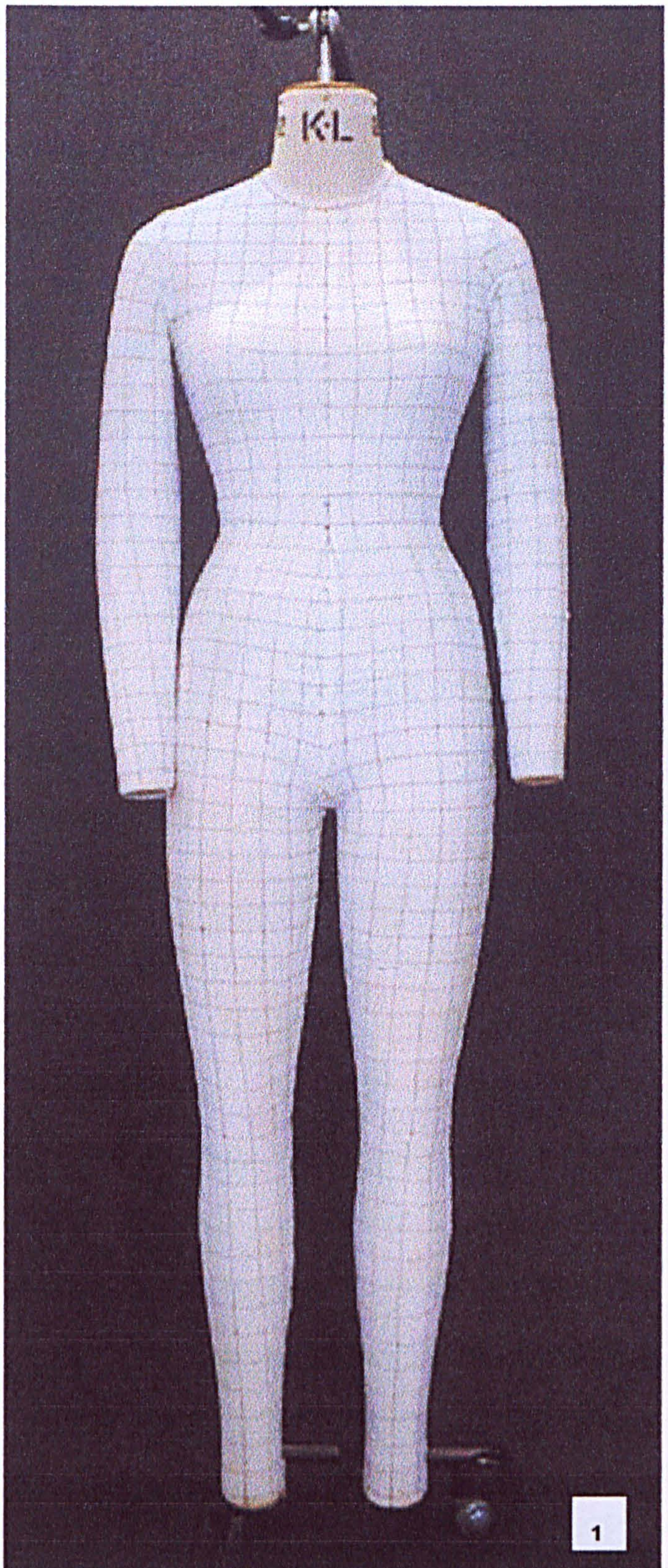


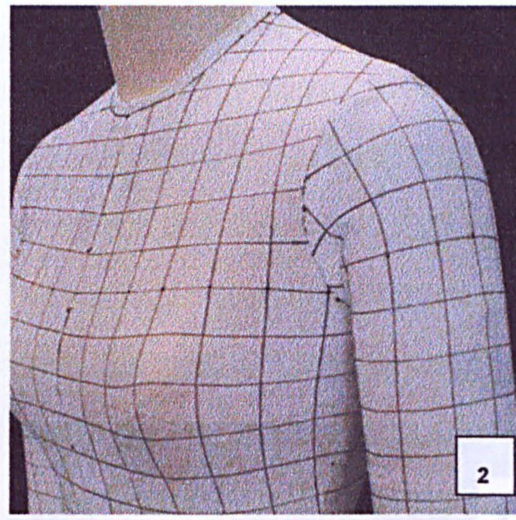
Figure 132-- Dolly Action Fit Bodysuit Fabric Sample D Back View

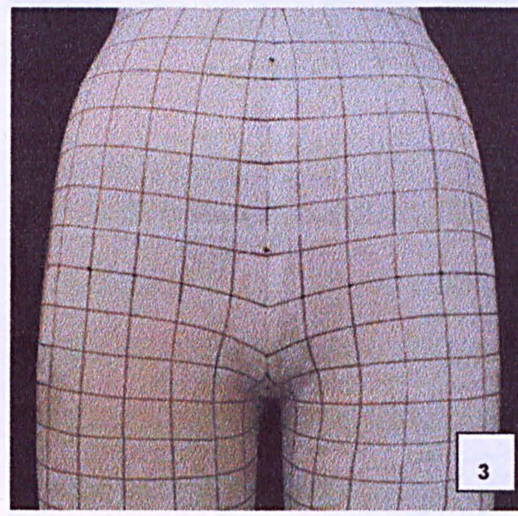
5.9.4.8 Dolly, Action Fit Bodysuit Fabric Sample E Evaluation Chart and Area Photographs

Name: Dolly		**Garment**: Sample E		
Area	**General**	**Wrinkle**	**Tare stretch**	**Stretch**
1-Front	Very good	None	Minimal	Rectangular
2-Front armscye and chest	Chest very good, arm good	Unavoidable but minimal	Predictable chest trapezoids	Rectangular chest trapezoids
3-Bodyrise and top thigh	Very good	None	Rectangular	Rectangular with rhomboids orientating towards fork level
4-Back	Very good	None	Minimal	Rectangular
5-Shoulder and crown	Very good	None	Rectangular, square at crown	Enlarged squares
6-Back armscye and shoulder blade	Very good	Unavoidable but minimal	Slight trapezoid under shoulder blade	Rectangular with rhomboids orientated towards under arm
7-Seat and top thigh	Very good	none	Minimally enlarged squares and trapezoids	Rectangles on top hip, seat enlarged squares, rhomboids at under seat and top thigh orientated towards seat cleavage
Comments: Unable to manipulate the dress stand into the defined position. The arm shape and positioning is particularly unrealistic. Overall fit very good.				

Table 24 - Dolly, Action Fit Bodysuit Fabric Sample E Evaluation Chart







DOLLY			
Fit Factor		**Axis Ratio**	
Action	.75	Course	2
		Wale	7
Fabric			
Sample	E		
Quality	21130		
Desc	32gg 180g Coolmax/Lycra		
Polyester	84		
Elastane	16		
Colour	White SDI5243		
Hanger Load		**Reduction Factor**	
Course	50	**Course**	0.92
Wale	28	**Wale**	0.81
Bias	51		

Figure 133 - Dolly Action Fit Bodysuit Fabric Sample E Front View

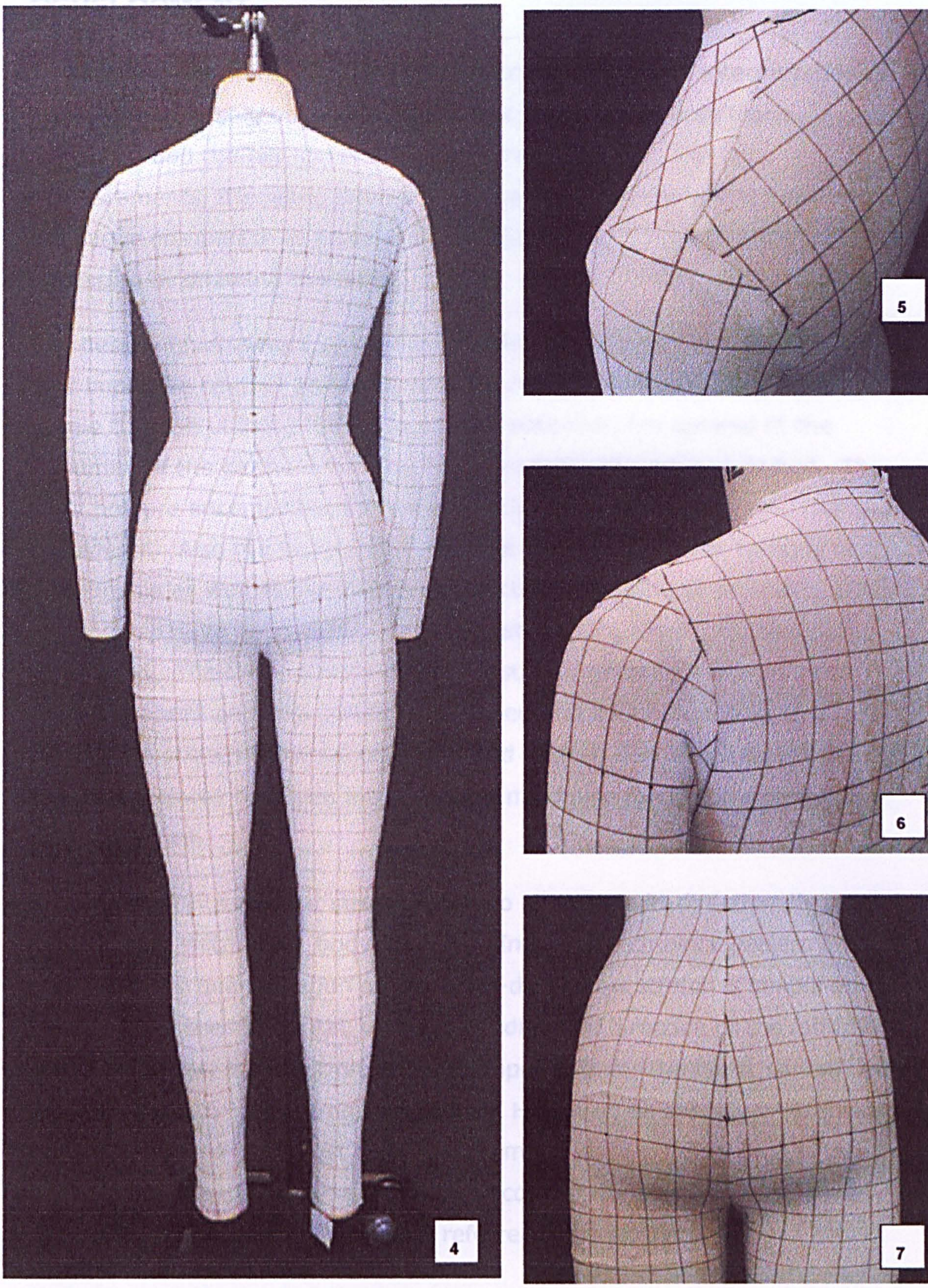


Figure 134 - Dolly Action Fit Bodysuit Fabric Sample E Back View -

5.10 SUMMARY OF STRETCH BLOCK PATTERN DEVELOPMENT

The new stretch block pattern has been achieved through interpretation of the interrelationship between the dynamic form, the stretch fabric behaviour and the two-dimensional pattern geometry. The body measurements, the fabric stretch characteristics and the pattern drafting technique co-operate to achieve a fit quality to facilitate movement without displacing or straining the fabric.

The design development process is complex and it is the interrelated factors that impel the contour fit quality relationship between pattern and body profile through utilising the fabric stretch potential. For optimal fit the proximity of the garment-to-body fit relationship has been identified. The body posture encompassing a range mobility to be accommodated has been considered. Also the factors that promote a quality garment-to-body fit relationship as well as the undesirable factors that impinge on that relationship have been outlined and a strategy for garment fit analysis introduced. The fabric stretch characteristics of geometric shapes have been visualised and interpreted and applied and a key to identify the observable stretch deformation in the grid pattern delineated on the analysis garment has been introduced to maximise the fabric stretch characteristics.

It is the ability of the knit stretch fabric to stretch multi-directionally that makes them suitable for body profiling. In the stretch block pattern drafting procedure the quantification of this multi-directional stretch is simplified by measuring in the horizontal, vertical and diagonal direction of the fabric and the quad hanger load test provides the input data for the fabric course, wale and 45° and 135° bias stretch extension. However, as the fabric extension has to be applied using just two measurement, the bias extension is the average between the course and wale becoming the course/bias and the wale/bias extension measurements referred to as bias vectors.

In its simplest form a body contouring garment could be constructed from cylindrical shapes of stretch fabric, of varying circumferences and lengths, covering the arms, legs and torso. Movement in any area of the body has to be accommodated by utilising available fabric stretch and generally must be greater than free body expansion. Therefore, the length of the body to accommodate maximum elongation will require the fabric to be reduced by a different proportion to the circumference of the body which is not subject to the same movement excesses. This variable is referred to as the axis ratio.

Garments constructed for a variety of applications will require differing fit levels. A form fit should contour the body without stretching, an action fit would exert some pressure on the body and a power fit would apply even more pressure. The fit factor variable allows different fit level categories to be accommodated.

The pattern orientation aligns the length of the body in the direction of maximum stretch extension. The reduction factor takes an amount of the available stretch for the appropriate fit level. This fit factor then determines the amount of the available stretch to be applied by the axis ratio which allocates the amount of available stretch by different proportions to the vertical and horizontal pattern profile.

5.10.1 Stretch Block Form Fit

A form fit garment presupposes that the garment fabric will follow the body contours. In areas of protrusion a limited amount of available stretch is used to contour to the body. There is an obvious connection between body shape and stretch deformation and this is a complex relationship which is highlighted by the application of a grid pattern on the garment to be observed.

Dolly's positive attributes as a consistent development tool were that her posture did not alter over time also her weight did not fluctuate and she was always available for a fitting! However, a dynamic assessment was not possible and the inanimate Dolly, with her rigid posture and contours, was the cause of much frustration in the stretch block pattern development process. Obviously there were no reflections on comfort and mobility and a canvas surface does not have the properties or malleability of human skin and the lack of body warmth affects the garment analysis. Warmth in the human body changes fabric behaviour causing the fibres in the fabric to relax and mould to the body. Any disparities in fit are exacerbated by movement, which highlights any potential problems. The arm, the shoulders, the bodyrise and the fork level areas on Dolly posed major difficulties when developing the stretch pattern, because of their general shape and the way these limbs are attached to the dummy.

Overall assessment of how closely the toile conformed to the body and the areas of stress, strain, wrinkle and stretch deformation were observed and other than the tare stretch predicted, no undesirable stretch occurred. The predominant shape of the grid pattern was square except in areas of protrusion, where the stretch enlarged the squares or distorted them to rhomboids and trapezoids all of which were acceptable.

The stretch block form fit achieved successful results in conforming closely to the body contours in preparation for the pattern reduction process.

5.10.2 Stretch Block Action Fit

The stretch block action fit describes those garments where the stretch characteristics, under tension, effectively hold and support the body. The grid printed on the stretch fabric was used as a visual reference for observing the stretch factor, which is a function of the pattern orientation on the fabric, the directional stretch, the proximity of the garment to the body and the geometry of the pattern profile.

The grid system allows the assessment of the stretch distortion characteristics in individual squares, it shows how the stretch characteristics vary as the geometry of the toile conforms to the contours of the body. Key areas of the toile were analysed and evaluated to determine optimum application of the course, wale and bias stretch theories to enhance the fit quality of the pattern profile geometry for freedom and comfort.

The available stretch in each direction of the course and wale for a given fabric will usually be different. Understanding the stretch behaviour is an essential part of predicting the pattern orientation to enhance the fit quality for comfort and to facilitate movement without displacing or straining the fabric. This is achieved in part by maintaining the stretch extension within the lower modulus working range and was calculated using the Quad

Hanger Load Test method developed in this research to make it easier to quantify fabric stretch in the pattern reduction.

If a fabric were to behave as a simple lattice structure that had very limited stretch in the course and wale directions, the resulting Quad Angle plot would be represented by four vectors radiating from a central point. Stretch fabric that extends uniformly in all directions for a given load would be circular. However, not all the stretch knit fabric samples have a corresponding degree of stretch between the bias at 45° and at 135°.

The Bias Vectors of the Quad Angle Plot were invaluable in the understanding of the distribution of fabric stretch characteristics. The garments found to have a good fit for comfort and mobility were samples B and E, with the bias stretch contribution to the wale being greater than bias contribution to the course.

The pattern orientation can affect the garment fit if the stretch fabric extension in the course and wale directions is different. Thus, if a pattern profile designed for a horizontal (course) orientation on the fabric is placed in the vertical (wale) orientation or vice versa, a garment-to-body fit disparity would occur.

Wrinkles should be minimal in the Action Fit garment if the form fit has been through the complete process of analysis evaluation. The stretch reduction factor, the Axis Ratio, is applied as a ratio of 7:2 and determines the scaled reduction of the pattern profile. The larger factor is the horizontal reduction, which was applied in the wale or direction of the minimum stretch. Factor two is the vertical reduction, which is applied in the course or direction of the maximum stretch. Therefore, with this Axis Ratio and pattern orientation the square extends horizontally to form a rectangle. In areas of protrusion the observable shapes were rhomboids and trapezoids, although the grid could also be analysed in terms of mean and standard deviation measurements and compared against a reference grid of 2.5cm. The contribution towards visual analysis of the stretch characteristics in this study would be minimal, although it might be beneficial when evaluating the power fit of compression garments.

The fit of the upper arm section was assessed after the arms were moved multiaxially on three planes (swung around) and the fabric conformity in relation to the body had reached equilibrium. The stretch fabric moves as the arm is moved and the garment becomes anchored at the intersection between the body and the arm. If depth of the armhole is too deep, it will encroach on the torso area under the arm outside the armscye line and as the arm is raised, the body of the garment will ride up to conform to the underarm area. Therefore, the depth of the armhole is a crucial measurement.

The impact of movement on stretch fabric is evident as the leg returns to the standing position after a sequence of body flexion, extension and hip rotation. The stretch characteristics of the fabric allow the body to move. However, it is the pattern geometry of the waist, hip, thigh, bodyrise and fork level, together with the proportion of the available stretch utilised within the low modulus working range of the stretch fabric, that will determine whether or not the stretch characteristics conform to the body after movement, without the need for garment-to-body re-adjustment.

The movement evaluation (see accompanying video Action in Motion) of the stretch block action fit toile reflects the cognition and transposition of the design ideation process to date. Good fit is dependent on the pattern drafting co-ordinates co-operating with the stretch characteristics, thus conforming to the shape of a person. It will be observed in the video when Fiona performs a series of movements designed to fully extend the body and flex the fabric that, as the body moves through the various movement sequences, the pattern profile geometry co-operates with the fabric stretch characteristics, extending and retracting to follow the body contours without displacing or straining the fabric. This is apparent particularly when viewing the fabric in the areas around the armscye and crutch where it will be noticed that the fabric moves in harmony with the body, without displacement, during and after the series of movements like a second skin.

Replicating the size and shape of a person in the pattern profile is the key to the dynamism of the stretch block form fit pattern and retaining the pattern profile contour curves has a significant influence on the garment fit quality. The pattern profile is achieved through a combination of delineating the body contour levels along a vertical axis, and then using the somato offset at the corresponding level as the foundation for the placement of direct body measurements.

The Stretch Block Pattern represents the three-dimensional body shape in a two-dimensional pattern profile. The geometry of the Stretch Block Pattern contours the body at the Form Fit Level. The Stretch Block Action Fit Level is determined by the proximity of the stretch fabric to the body, and requires the reduction of the pattern profile to maintain the stretch potential within the low modulus working range. It has been shown here that it is the fabric stretch characteristics, inextricably linked with the pattern profile, which adjust in unison with movement to contour the body, without displacing the fabric.

CHAPTER SIX

CONCLUSION

6.1 CONCLUSION

This stretch block pattern has been conceived as a consequence of personal experience and an understanding of factors highlighted in research to date. The idea was gradually formulated using analysis of garments, patterns, stretch fabric characteristics, body shape and proportions, posture and movement and performance requirements.

Whilst studying pattern geometry and stretch characteristics it became increasingly apparent that existing pattern drafting techniques did not work. Making use of the grid system on stretch fabric to visualise fabric stretch characteristics gave a fresh glimpse into exactly why the pattern drafting techniques, divorced from the principles, were failing. Recognising the limitations was the first step towards a different approach which involved casting aside existing methods and returning to first principles, using the basic human form as point of reference.

It has been shown here that if a conventional pattern is only reduced horizontally and vertically by a percentage, with no other alteration to the initial pattern profile geometry, the resulting garment fails, as a design, to provide optimum mobility, comfort and fit. The factors that promote a quality garment-to-body fit relationship as well as the undesirable factors that impinge on that relationship have been considered. The importance of fit for comfort and movement in the stretch bodysuit can not be underestimated because ill-fitting, restrictive clothing can be both physically and mentally exhausting.

This practical study provides a more scientific approach to assessing fabric extensibility and curvilinear distortion. For optimum comfort and mobility the direction of maximum fabric extension corresponded to the length of the body and, as a general rule, the width of the pattern was reduced proportionately greater than the length because it is not normally subjected to the same stresses. Stretch reduction is related to garment extension in wear and the stretch potential of the fabric was retained in the low modulus region. This brought the hugging power of the fabric into play and allowed the garment, when stretched over the body during movement, to cover rather than retract, thus eliminating garment displacement.

First the fit level (form, action or power fit) was established then the fabric stretch extension was quantified. Using a bias vector calculation this was then applied using an axis ratio reduction factor and optimum pattern orientation. The stretch block form fit was constructed using direct body measurements, including a precise fork point positioning measurement. The body (in all its multiformity) was the reference for the pattern profile geometry and the resultant curved contour pattern profile used was significantly different to modified and rationalised conventional pattern profiles for stretch fabrics.

The aim of the study was to create a new stretch block pattern that would ensure a good fit, first time, every time, during and after an extensive range of movement. The pattern drafting approach combined direct body measurements and stretch fabric parameters optimised by the pattern orientation. The new stretch block pattern closely contoured the body in a form fit and the pattern reduction was classified according to a body-proximity, action fit level category. The block is then ready for performancewear design development.

This approach significantly reduces the margin for fit error and promotes *EASE* of *MOBILITY* and *COMFORT*. It was found that the *NEW* stretch block pattern required no modification and the test garments were constructed and worn without the subjects needing a rehearsal fitting of the bodysuit.

During extensive movement the subjects experienced no fabric displacement and they found the bodysuits did not need any adjusting to the body when motion ceased. The subjects found that the bodysuits were comfortable and easy to wear at all times.

Examples of bodysuits B and E worn by Fiona have been illustrated in 'Action Fit in Motion', which is the demonstration video to accompany this study.

6.2 FURTHER WORK

This area of research is challenging and has highlighted many more questions than answers.

Over the years manufacturers have tried to standardise on garment sizing. However, the industry is moving towards greater automation and is embracing the concept of individual garment production using computer-generated patterns based on the measurement co-ordinates of the customer. The developing technology for body scanning can only be beneficial because it is far less intrusive and often more time and cost effective than using manual tape measure techniques. Specialist computer technology for pattern development will rely on incontrovertible anthropometric data and accurate mathematical modelling to improve the quality of sizing and fit models. However, the resultant garment fit quality is still dependant on the pattern drafting procedure replicating the predicted garment-to-body fit expectation.

The areas of note are:

- Somatometry
- Garment pressure
- Quad angle distribution

6.2.1 Somatometry

In conventional patterns the relationship between the body measurements and the body shape and the pattern profile is usually implicit in the drafting procedure rationale and there is a tendency to rationalise the pattern profile by actuating the contour geometry into straighter lines and more fluid curves. It is the shape and proportion of a person that is significant and reproducing the three-dimensional body contour in a two-dimensional pattern profile can be problematic.

The optimal distribution of the somato offset and the development of pattern systems based on direct somato physical data requires further research to produce garments for somato categories. Further research on the quantity and location of the measurements and pattern generation technique created in this study could also be refined to further improve fit models for different somato types either for an individual or a specific target market.

6.2.2 Garment Pressure

An understanding of garment pressure is an essential part of predicting the fit level, to retain the stretch extension within the lower modulus working range.

Further exploration into fit, the effects of pressure and the radius of curvature, using the new stretch block fit levels, could possibly be pursued by impregnating the fabric with an electronic grid system to record garment pressure variation. The advantages of this 'smart' fabric would be the provision of both physical and visual data for situation specific garment pattern development.

6.2.3 Quad Angle Distribution

The quad angle stretch distribution plot is invaluable to the understanding of the distribution of stretch fabric characteristics. Bodysuits found to have a good fit for comfort and mobility were Samples B and E, with the bias stretch contribution to the wale being greater than the bias stretch contribution to the course. Co-operation occurs between the fabric directional stretch distribution and the modulus to contour the body, adjusting in unison with movement, without displacing the fabric.

The fabric stretch symmetry highlighted by the quad angle distribution plots and the implications for future garment fit needs further exploration because it could contribute to the improved performance profile of the stretch knit fabric.

6.3 SYNTHESIS

It is hoped that the work illustrated in this Thesis will enable Clothing Manufacturers and Designers, working in stretch performancewear, to achieve improved fit quality, comfort and performance levels.

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